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# technology review

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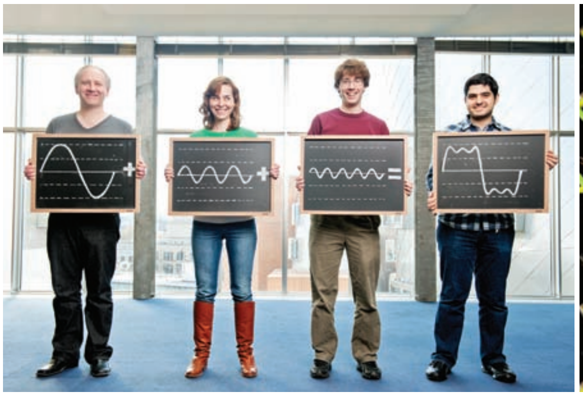
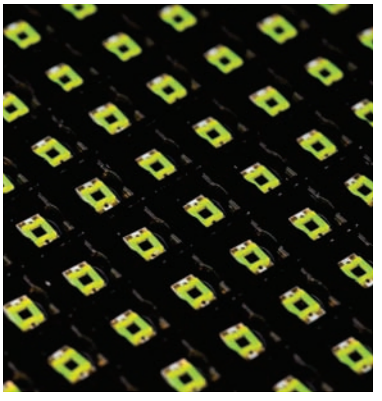
EMERGING TECHNOLOGIES







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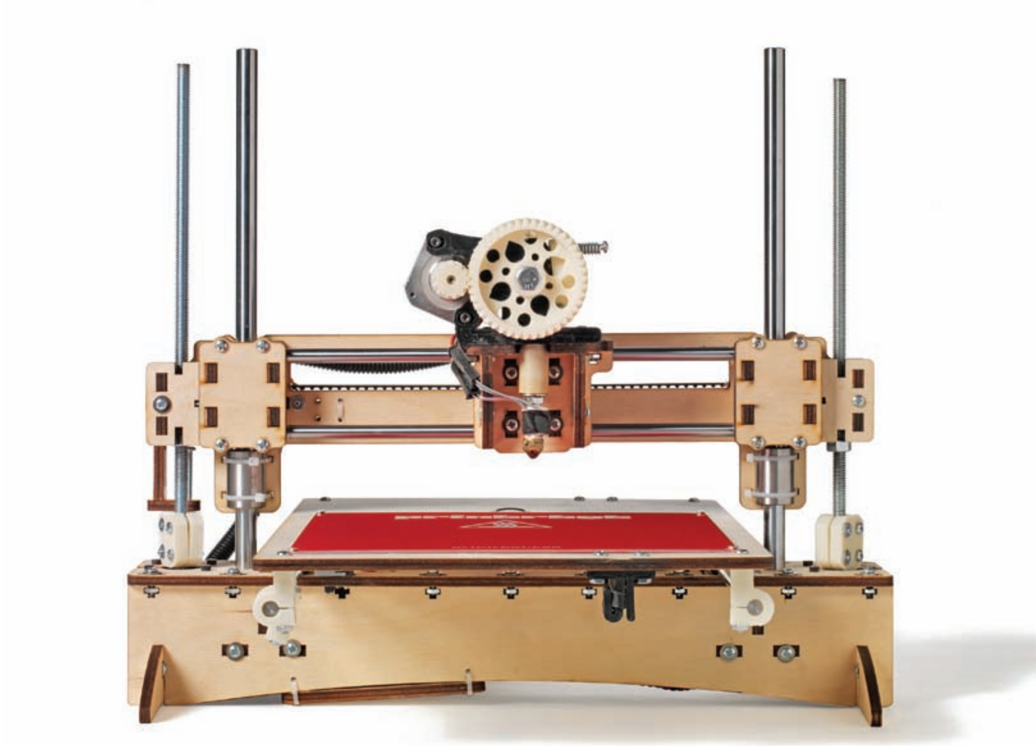
VOLUME 115, NUMBER 3





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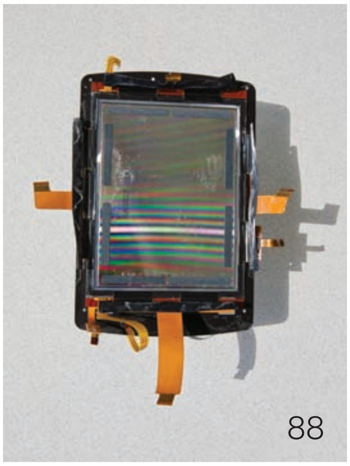

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*De Technologia non multum scimus. Scimus autem, quid nobis placeat.*


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# feedback

**"Turing's Enduring Importance," March/April 2012**

> "There is a growing mentality that due to his having been treated atrociously … he deserves to be elevated to the echelons of Newton or Leibniz."
>
> *Soma*

**GETTING TESTY OVER TURING** Simson L. Garfinkel's review on the legacy of Alan Turing ("Turing's Enduring Importance," March/April) drew an immediate—and sometimes vehement—response from readers. "The article's thesis—that his work made computing possible decades before it otherwise would have happened—isn't even close," declared **dtutelman** in an online comment. "Turing's contribution was not in the early development of computers so much as in the understanding of what they can and can't do, and the theoretical underpinnings of these pragmatically designed machines."

**Soma** had even harsher criticism, calling the piece "drivel." "There is a growing mentality that due to his having been treated atrociously by the British government he deserves to be elevated to the echelons of Newton or Leibniz, as if Turing were the only intelligent person in mathematics during the World War II era."

**Elroch**, on the other hand, felt that Garfinkel's appreciation was completely justified: "The notion of computability and the notion of a universal computer are tremendously important and powerful ideas for which Turing has to be given a great deal of credit. His work pointed the way to a sort of architecture for a general computer (central processor plus storage) which may seem utterly obvious now, but which was a radical departure from the architectures of computing machines before his time. I can't see why anyone would wish to downplay the significance of this pivotal work."


*March/April 2012*

**LEADING FROM BEHIND** Our chief correspondent, David Talbot, traveled to Africa to investigate how local startups were tapping the vast promise of cell phones to improve local health care ("Kenya's Mobile Prescription," March/April). "Great article!" wrote **Navi Radjou**, coauthor of *Jugaad Innovation*, a new book suggesting that Western companies should take inspiration from entrepreneurs in emerging markets. "Grassroots entrepreneurs have learned to do more with

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less by leveraging 'human networks.' What counts is the resilient and frugal mind-set of these entrepreneurs, who see scarcity as an opportunity to innovate rather than a constraint."

**NET MINDER** In March/April's "A New Net," IT editor Tom Simonite took a closer look at how a TR50 company, Nicira, hopes to solve one of network computing's most intractable problems: its weak security. Such a solution is "long overdue," felt **olinhyde**. "It is awesome to see Nicira create an elegant solution to the problem of network security. The simplicity of Martìn Casado's approach underscores the pathetic state of network security and the absence of innovation from incumbents like Cisco, Juniper, etc. Yet again, we see that the entrenched interests of the status quo prevent the possible from becoming reality. Let's hope Nicira can break through the barriers."

**HEAL THYSELF** An Internet pioneer named Larry Smarr turned himself into a pioneer of a different sort by mining data about his own health—and using that information to improve it ("The Patient of the Future," by Jon Cohen, March/April). "Interesting," wrote **colne**. "Good to get extensive baseline data, but what we really need is data from people in specific clinical populations. Then we could start to correlate outcomes and figure out optimum practice. Frustrating that it's taking so long to get this going. The same is true of lifestyle and prevention. We are not going to get the total cost of health care down by focusing on chronically ill patients; we need to motivate large numbers of people to get as excited about being fit as they are about preserving the environment, for example."

**CORRECTION** The world's carbon dioxide emissions from electricity and heat production rose from 9.1 billion metric tons in 2000 to 11.8 billion metric tons in 2009. Our Graphiti in March/April erroneously gave the figures in millions. tr

LIBYA

# Connected Conflict

The Internet amplified but did not create the bravery that freed Libya, says Moez Zeiton.

In July last year I traveled to Libya's Nafusa Mountains, around 150 kilometers southwest of Tripoli, with a group of Libyan expat doctors. We helped local medical staff set up mobile field hospitals wherever an armed front arose, providing trauma care, life support, and first aid.

Resources were limited across the mountains, with supplies available only via the Dheiba-Wazin border crossing into Tunisia. Yet we had another supply line that was less tangible. Local youths set up Internet-connected media centers in almost every town to document and catalogue photographs and videos and track events in their region. The centers also acted as proxy bases for international journalists and correspondents visiting the region and helped them spread our story around the world *(see "People Power 2.0," p. 62)*.

The media centers had basic equipment: simple PCs and digital cameras. But Libyan youths were creative, editing footage of the conflict into montages uploaded to popular YouTube and Facebook channels.

As Libyans watched Tunisia and Egypt erupt in protest, we knew that our own revolution would be less connected. Free press was nonexistent in Libya, Internet penetration was very low, and what few media outlets existed were plagued by censorship. Qaddafi's regime underlined that by imposing a complete Internet blackout.

The blackout didn't stop the media centers, though. Satellite equipment was used to upload footage and keep us and journalists abreast of the situation in other areas of the country. It also allowed Libyans to tell expats of major needs.

Even in these trying conditions, every medium-sized town in the Nafusa Mountains had a media center of some kind. The largest was in Zintan, where all international correspondents spent at least some time and received free food and (very slow) Internet access. One town, Nalut, even operated a radio station after taking over a building used by Saif Qaddafi, Muammar's son, fitted with up-to-date radio studios.

The term "Facebook revolution" has become common as the international community tries to wrestle activity in Libya and elsewhere into a comprehensible historical event. Libyans did not risk their lives for free speech and dignity because of the Internet, Facebook, or Twitter, but these technologies provided a vital channel through which to communicate inside and outside the field of conflict. That made these revolutions unlike any that came before, even in Libya, which lagged other nations in the region technologically. For the international community, the ephemeral, real-time stream enabled by that technology provided the most compelling narrative. It might not be accurate for Libyans to label their uprising a "Facebook revolution," but the term may be appropriate for Western spectators.

MOEZ ZEITON IS A DOCTOR AND A FOUNDING MEMBER OF THE SADEQ INSTITUTE, A NEW THINK TANK IN TRIPOLI.

KNOWLEDGE

# Many Libraries

As the world's books go online, we must resist centralization, say Brewster Kahle and Rick Prelinger.

The Internet has put universal access to knowledge within our grasp. Now we need to put all of the world's literature online. This is easier to do than it might seem, if we resist the impulse to centralize and build only a few monolithic libraries.

Centralization can lead to price controls, censorship without due process, lack of reader privacy, and resistance to innovators. We need lots of publishers, booksellers, authors, and readers—and lots of libraries. If many actors work together, we can have a robust, distributed publishing and library system, possibly resembling the World Wide Web.

The courts struck down as monopolistic an attempt by top libraries and Google to build a massive e-book collection. They proposed a collective licensing system, the Book Rights Registry, that would have the right to license exclusively to Google any book not claimed by an author or publisher. It would have limited options for readers. Now some proponents of the nonprofit Digital Public Library of America (DPLA) are encouraging legislative action that we fear might lead to a similar collective licensing approach *(see "The Library of Utopia," p. 54)*.

The DPLA should instead be helping nurture the seeds of a distributed library and publishing system—seeds that have already been planted.

All libraries could lend e-books, just as they lend physical books, avoiding a dependency on centralized databases. Libraries are already buying as many e-books as they can, and even small libraries can offer large collections: a single hard drive can hold over 150,000 books (as search-

NICK REDDYHOFF

able color PDFs) and their catalogue data. It is not difficult to lend books digitally, as technologies used by Netflix and Amazon show. Patrons of thousands of libraries can already borrow over 200,000 purchased and scanned e-books free from the Internet Archive. Most large publishers have recently banned e-book sales to libraries, but we hope this restriction is temporary.

Even as we acquire current e-books, we need to scan existing ones, but again, this work is already under way. We scan 1,000 books a day at 31 libraries in seven countries with funding from libraries and foundations. Scanning centers such as those at the Boston Public Library and the Library of Congress digitize hundreds of books a day. Libraries working with the Internet Archive have already put over two million public-domain books online for free downloading and lending, and for use by people unable to read printed books.

Now is our chance to build an online library accessible to all. To equal the Boston Public Library or university libraries like those at Yale or Princeton, we need 10 million books. These could be acquired in four years for approximately $160 million. The DPLA, with its broad support, can help build this library system, or it could end up building an overly centralized library by using collective licensing systems like the Book Rights Registry.

If we work together, we can achieve universal access to knowledge by building on the positive lessons of the Internet and World Wide Web.

BREWSTER KAHLE (PICTURED ABOVE) IS THE FOUNDER OF THE INTERNET ARCHIVE. RICK PRELINGER IS AN ARCHIVIST, WRITER, AND FILMMAKER.

MATERIALS

# Competing Faster

We need to accelerate the deployment of advanced materials, says Cyrus Wadia.

The Boeing 787 Dreamliner elicits awe, envy, and the question "How did they do that?" It is 20 percent more fuel efficient than previous comparable airliners, its cabin is more spacious, and its windows dim with the touch of a button. Fully explaining how it was done is complex, but the first part is simple: it's all about advanced materials. A body and wings made from a carbon fiber composite confer enhanced fuel efficiency, for example, while the windows incorporate an electrochromic gel.

Most people don't realize that it can take 20 years or more for a newly discovered material to be incorporated into commercial products. Lithium-ion batteries were proposed in the mid-1970s but were not broadly adopted until the late 1990s. Superconductors, solar photovoltaics, and solid-state lighting emerged over similar time frames. That is far too long given the role advanced materials could play in addressing many of the nation's most urgent needs *(see "High-Speed Materials Discovery," TR10, p. 48)*.

Once a new material is discovered, the current best practice for tailoring it to the market is a long sequence of steps involving many repeated experiments. Each step serves a different purpose, such as property optimization or process scaling. Engineers have to grapple with and ultimately control dozens of electrical, chemical, and mechanical properties.

Predictive software models could complement and in some cases replace this time-consuming experimentation, but such tools are lacking. To make matters worse, an overly proprietary and fragmented community inhibits a culture of sharing knowledge, data, and tools. As a result, good inventions lie dormant, and development cycles remain linear and slow.

In the case of the Dreamliner, Boeing realized that materials development didn't have to be linear. The company unified its multinational supply chain into a single virtual design platform. Design changes made in Japan became immediately visible to partners in the United States, and a global team cycled through thousands of designs before a single screw was turned. This kind of collaborative, networked approach could revolutionize and significantly speed up the process.

Last year, President Obama launched an ambitious new program called the Materials Genome Initiative, which aims to help the U.S. materials community foster similar approaches. But while the federal government can encourage change, it will be up to scientists to put this new vision to work.

Over the past two decades, advances in nanotechnology have given us the tools to synthesize, characterize, and model materials at the nanoscale—the scale at which materials' behavior can be controlled. We need to nurture an accompanying national infrastructure for materials development in computation, experimentation, and data informatics. Combined with a more open, collaborative approach, these tools will accelerate the discovery and deployment of advanced materials. tr

CYRUS WADIA IS ASSISTANT DIRECTOR FOR CLEAN ENERGY AND MATERIALS R&D IN THE WHITE HOUSE OFFICE OF SCIENCE AND TECHNOLOGY POLICY.

# 10 Emerging Technologies

They promise to change the world. But how will their development be funded?

Every year, the editors of *Technology Review* pick the 10 emerging technologies we think are most likely to change the world: the TR10. Other lists we publish, such as the TR35, our annual list of 35 young innovators under the age of 35, are less subjective: innovators nominate their most admirable young peers and colleagues, and a panel of distinguished judges grades the nominees. The TR10, by contrast, reflect our judgments. We consider the major technological domains and award recognition to the breakthroughs "that we believe will have the greatest impact on the shape of innovation in years to come" (to quote the editor of the TR10, *Technology Review*'s special projects editor, Stephen Cass).

The technologies are always various. This year's TR10, which appear starting on page 33, include a fertility technology developed by Jonathan Tilly of Boston-based OvaScience, in which stem cells in ovarian tissue could be coaxed into forming new eggs or rejuvenating a woman's existing eggs; the light-field photography of Lytro, a startup in Mountain View, California, which has reinvented the camera by capturing three-dimensional patterns of light that software can manipulate to stunning effect; solar microgrids, cheap solar panels and LEDs combined by Mera Gao Power of New Delhi, India, to provide clean light and charge phones in the rural subcontinent; and an alternative to traditional venture capital funding called "crowdfunding," created by the New York–based website Kickstarter, which encourages communities of enthusiasts to fund new projects with small sums.

Amid all this celebration of emerging technologies, a few words of mild caution are appropriate. How will these technologies be funded and commercialized? Kickstarter, for all the interest it has attracted, is an experiment that (so far, at least) has funded mostly experiments that don't require much money.

Traditional venture capital, as it evolved in Silicon Valley during the 1970s and '80s and flowered in the '90s, was supremely well suited to funding new information and Web technologies during an era when the public markets were exuberantly receptive to the stock offerings of new IT and Web companies. With great difficulty and mixed success, Silicon Valley–style venture capital was applied to funding biotechnology: large pharmaceutical companies, hungry for blockbuster drugs, would pay licensing fees that justified initial public offerings and acquisitions of biotech startups.

But venture capital struggles to help commercialize other emerging technologies. As David Rotman writes in "Can Energy Startups Be Saved?" *(p. 83)*, venture capital is "ill suited to creating energy companies on its own." And taken as a whole over the decade since the dot-com bubble burst, venture capital hasn't even been very effective at funding new information and Web technologies *(see "What's Wrong with Venture Capital?" March/April 2010)*. A successful public offering of Facebook's stock will make it easier for other Web and IT startups to repay their investors and may repair venture capital's mode of business in limited domains; but if emerging technologies are to provide solutions for the big, civilizational problems in energy, health, education, and resource management, we'll need new mechanisms for commercialization.

But write to me at jason.pontin@technologyreview.com and tell me what you think. *—Jason Pontin*

MARK OSTOW

# to market

COMPUTING

## Robot Soldier

A HEAVY-DUTY MACHINE developed by iRobot, which has previously built a series of relatively small military robots used largely for reconnaissance, is capable of pulling a car or climbing over obstacles almost half a meter high. It can also be fitted with a rocket that drags a chain along the ground to clear a path through a minefield.

■ **Product:** 710 Warrior **Cost:** $300,000 to $400,000 **Availability:** Now **Source:** www.irobot.com **Company:** iRobot


IROBOT


COMPUTING

# A Screen for Every Occasion

WITH THE PadFone smart phone, there's no need to sync files and applications between a phone, a tablet, and a laptop, or to buy three separate devices at all. The Android phone slips into a larger screen, powering it as a tablet: the system will automatically let you continue working with whatever application you were using at the time you docked the phone. The screen, in turn, can be plugged into a keyboard, which doubles as an additional battery pack.

■ **Product:** PadFone **Cost:** N/A **Availability:** Fall 2012 **Source:** www.asus.com **Company:** Asus

COMMUNICATIONS

# Home Health Center

THE 2NET HUB provides a single collection point for the wireless data generated by a plethora of home health devices that use a variety of communication standards, such as Bluetooth, Wi-Fi, and ANT+. Data stored by the hub can be transmitted to a cloud operated by Qualcomm via a cellular connection, making it possible to share the information with doctors or insurers.

■ **Product:** 2Net Hub **Cost:** N/A **Availability:** Now **Source:** www.qualcommlife.com **Company:** Qualcomm



COMPUTING

# Transparent 3-D

THE FIRST Android-based see-through wearable display, the Moverio uses two micro-projectors to create separate images for each eye, allowing it to play 3-D movies overlaid on the wearer's view. In addition to videos, users can download Android applications via Wi-Fi and control them with a handheld track pad.

■ **Product:** Moverio BT-100 **Cost:** $700 **Availability:** Now **Source:** www.epson.com **Company:** Epson

ASUS (PHONE); QUALCOMM (HUB); EPSON (GLASSES)

COMPUTING

# Turning a Laptop into a Tablet

THE PT PEN can turn any laptop screen 16 inches or smaller into a stylus-based touchpad, allowing it to be used as a virtual whiteboard or sketch tablet. The PT Pen can also be used to annotate documents, and it works with the handwriting recognition software built into most operating systems. The position of the stylus is determined with ultrasound.

■ **Product:** PT Pen **Cost:** $199 **Availability:** Now **Source:** www.baldtechnologies.com **Company:** Bald Technologies

MATERIALS

# Illuminating Match

SORAA HAS DEVELOPED an LED that is bright enough to replace a 50-watt halogen bulb but draws only 12 watts. Most LEDs emit light from a thin layer of gallium nitride on a substrate of either silicon or sapphire. Soraa's Premium LED has a gallium nitride substrate instead; using the same material for the substrate and the emitter means more current can be run through the LED, resulting in more light output from a given area.

■ **Product:** Premium MR16 **Cost:** N/A **Availability:** Now **Source:** www.soraa.com **Company:** Soraa

SORAA (LIGHT); BALD TECHNOLOGIES (STYLUS)


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COMMUNICATIONS

## Cop Cam

DESIGNED FOR POLICE USE, this camera clips to a pair of glasses and records video evidence from the point of view of an officer. The camera has a continuously looping buffer, so at the moment the officer decides that an incident warrants recording, the previous 30 seconds are stored too. Live video from the camera can also be streamed to a smart phone.

■ **Product:** Axon Flex **Cost:** N/A **Availability:** Now **Source:** www.taser.com **Company:** Taser

COMPUTING

## A Feel for the Game

TOUCH-BASED GAMES have become wildly popular on smart phones, but they pose a dilemma: either fingers obscure some of the on-screen action or valuable screen real estate must be devoted to control areas. The PS Vita portable game console solves this problem by incorporating a touch pad on the rear of the device. This pad is particularly useful for augmented-reality applications, which can overlay digital information anywhere in the field of view provided by the built-in camera.

■ **Product:** PS Vita **Cost:** $300 **Availability:** Now **Source:** us.playstation.com **Company:** Sony


TASER (CAMERA); SONY (CONSOLE)


The people behind connections for sharing ideas.
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graphiti

# Bases to Bytes

Cheap sequencing technology is flooding the world with genomic data. Can we handle the deluge?

By MIKE ORCUTT

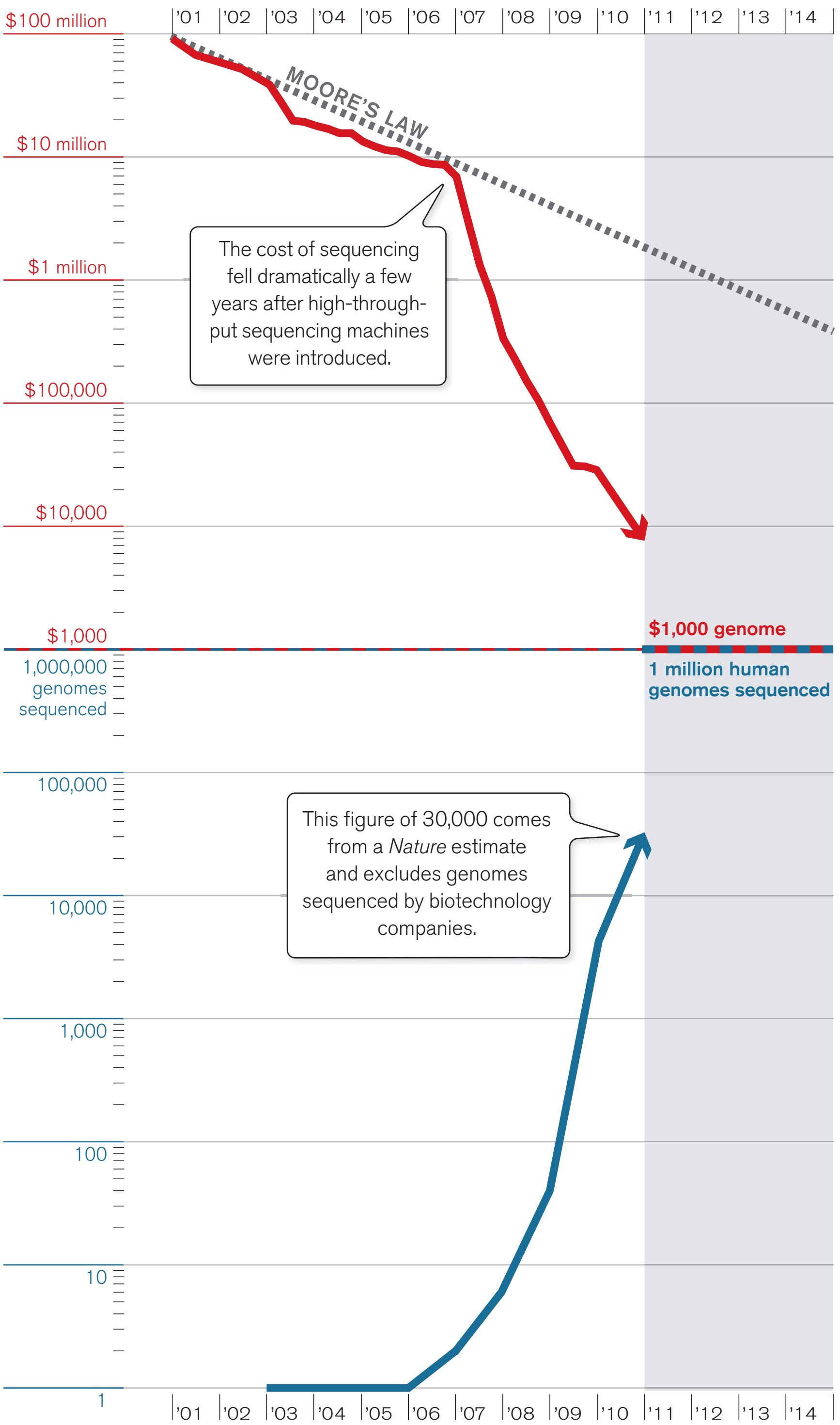
The cost of sequencing human genomes is plunging—in the most advanced genomics centers, it's falling five times faster than the cost of computing. Increasingly, people are getting their DNA sequenced by companies and research labs in a search for clues about genetic variation and disease.

But the industry must figure out how to cheaply store all the resulting data. Each of the 3.2 billion DNA base pairs in a human genome can be encoded by two bits—800 megabytes for the entire genome. But considerable data *about* each base is usually collected, and genes are often sequenced many times to ensure accuracy, so it's common to save around 100 gigabytes when sequencing a human genome with a machine made by industry leader Illumina. Keeping this much data about every person on the planet would require about as much digital storage as was available in the whole world in 2010.

The trick, then, will be to save less. Harvard geneticist George Church says that eventually only the differences between a newly sequenced genome and a reference genome will need to be stored. That information could be encoded in as little as four megabytes. Then your genome might be just another e-mail attachment.

## Sequencing Costs Plummeting, Output Skyrocketing

**Cost per genome and number sequenced**




Sources: U.S. National Human Genome Research Institute, *Nature*

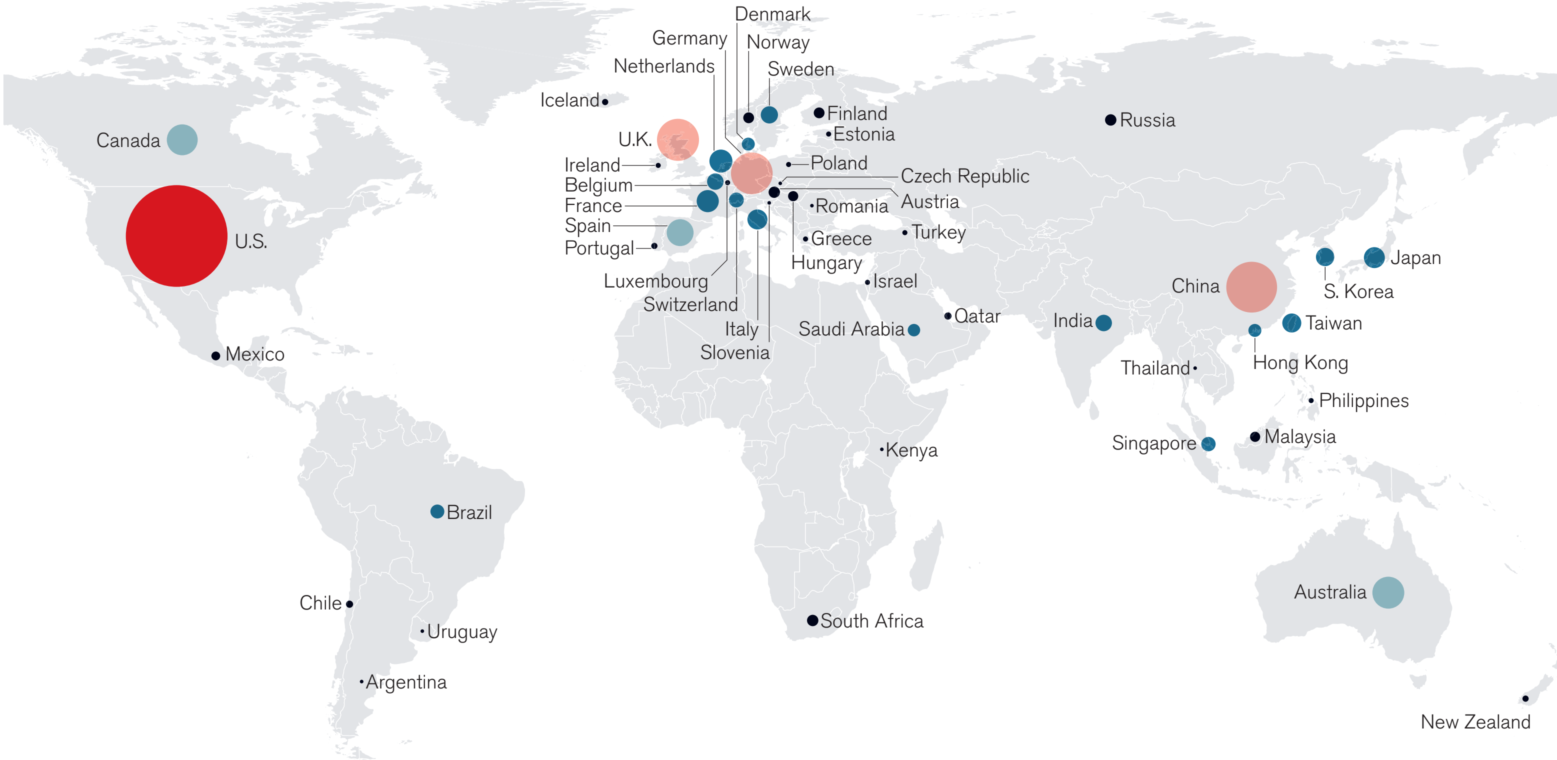
*Information graphics by* INFOGRAPHICS.COM

# High-Throughput Sequencing Goes Global

Approximate number of machines (by country)

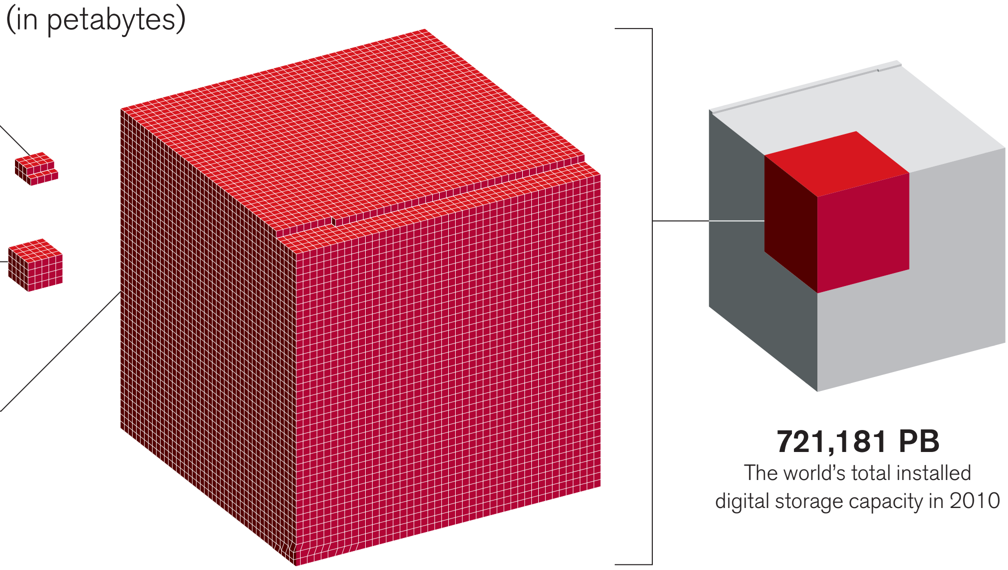
*The map is based on data from a user-generated database of publicly available statistics, representing 60 to 70 percent of all machines; it excludes biotech and pharmaceutical companies and some sequencing service providers.*

800+ | 101–200 | 51–100 | 11–50 | 1–10




# Data Storage Challenge

Digital information storage (in petabytes)



**28 PB**
The digital storage that would be needed to hold seven billion genomes at four megabytes each

**100 PB**
The amount of digital information Facebook stores in the form of photos and videos

**85,000 PB**
The storage that would be required if all 850 million Facebook users had 100 gigabytes of recorded genomic data

**721,181 PB**
The world's total installed digital storage capacity in 2010

Map source: omicsmaps.com; storage graphic sources: Illumina, Facebook, IDC

# Q&A

## Dave Morin

The creator of a social network for close friends and family says smart phones will make computing more intimate than PCs did.

Facebook and its competitors have given us virtual social circles unlike our real ones, lumping in work acquaintances alongside old friends. Dave Morin, an early employee of Facebook, launched his own company, Path, in 2010 to offer a social network just for close friends and family.

Path users can add only 150 people to their networks, and they access the service exclusively through a smart-phone app that evokes a personal journal. They log their "path" through life with photos and updates on where they are or what music they're listening to, all while reading about the paths of their friends.

Path has attracted over two million users and $11 million of investment funding. But the company was accused of violating its users' privacy this February when a blogger discovered that its iPhone app copied people's address books onto Path's servers without asking permission. Morin, 31, a respected figure in Silicon Valley because of his history at Facebook and recent record of investing in promising startups, was forced to apologize.

*Technology Review* IT editor Tom Simonite spoke with Morin about that incident and the benefits of private social networks.

***TR*: Why do people feel the need for a more private, more limited social network?**

Morin: If you ask people why they didn't put all the photos on their phone on Facebook, they say, "They're too personal." But people e-mail and text these photos to friends and family. The volume of that kind of sharing is really high, and we want to make that more high-fidelity.

Even today, whether they have 10 friends or 100 [on Path], people still say to us that they need more privacy.

**Why does it have to work only on a mobile phone?**

People actually communicate with a very small set of people using their phones. You text and call and share with your inner circle.

[And] I really buy Steve Jobs's notion that the future of computing is these things that we carry around in our hand. The future is not just phones; it's wearable computers that give you more data about your everyday life. Our job is to be a trusted place for that data and to give you beautiful visualizations and stories to add to your path about it.

**Path has a very striking, polished design. Why was that important?**

We felt that the Web was a very cold and utilitarian place, oftentimes. One of our highest design goals was this idea of a home. Your personal life exists inside a home, and there's this feeling of warmth and love that comes through being inside it. Mobile provided an opportunity to create this warm, colorful, deeply intimate place that you could trust.

**You have to make money, but you say you're opposed to the standard Web model of using everyone's data to personalize ads.**

We look to Asia, where a lot of networks, [such as] Mixi in Japan and 10cent [in China], provide a free service but allow you to personalize your experience in ways that users are willing to pay for. For example, we have a bunch of free photo filters, and then we have a series of paid ones. We want to say "Make your experience better—pay us directly" rather than "Give us all your data and we'll work with advertisers to get messages in front of you that you might not care about."

**What happened in February? An earlier version of your app didn't automatically upload users' contacts to your servers. Then you made a decision to add that feature. Why?**

The decision was based entirely on simplicity. We developed an algorithm that we call FriendRank, which looks at contact data [and] uses machine learning to figure out who might be your family and closest friends. Most social networks provide you with "Click this button and invite your entire address book," which spams everyone. We were using technology to crunch the data and present to the user who we think they should connect to.

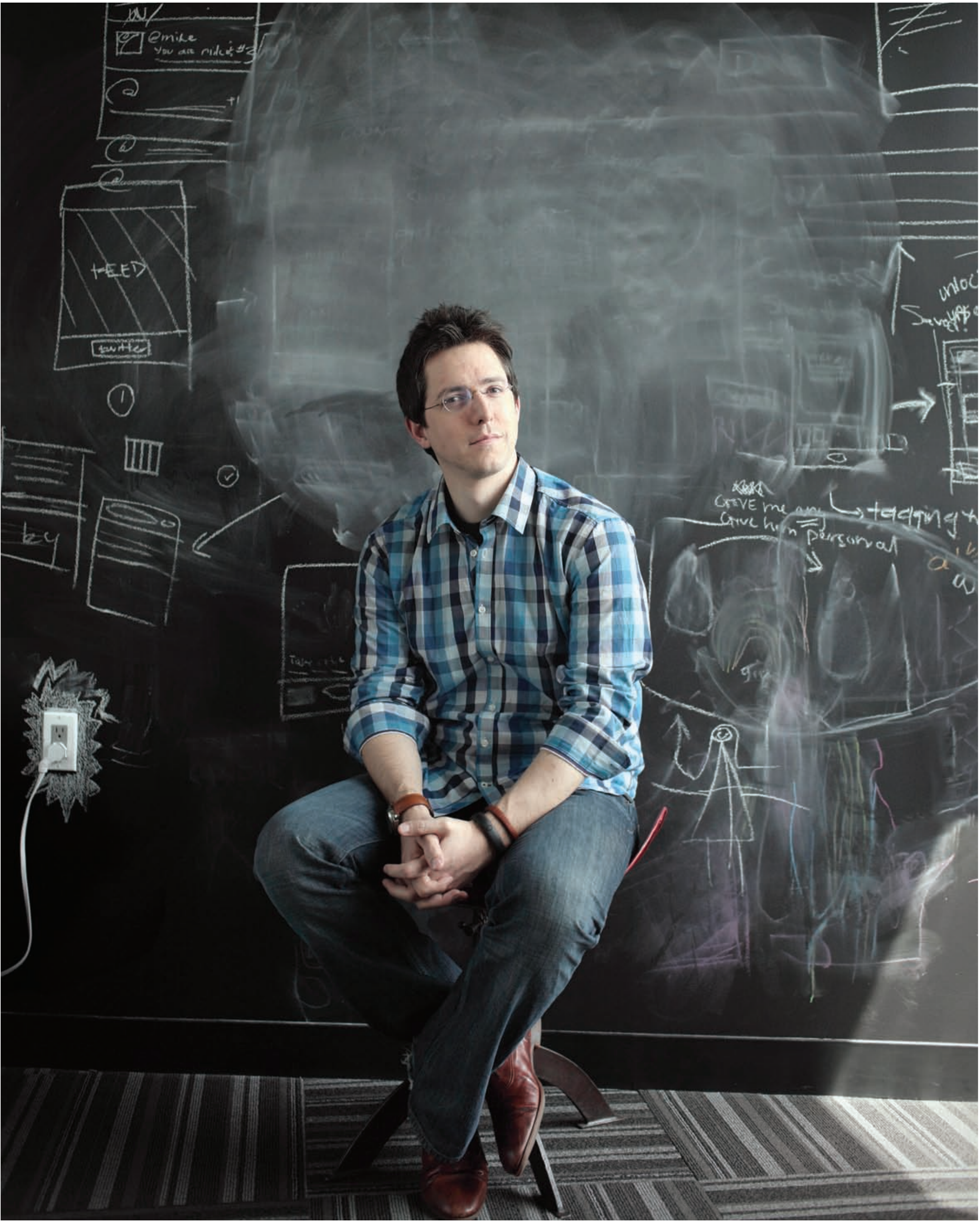
**But you were taking contact data from devices. You thought people would be okay with that?**

Yeah. And frankly, at that point it wasn't clear that people weren't okay with it.

When it became clear that this really bothered people, the only right thing to do was delete it all. We did it a day after. We created a dialog that says, "To help you find your close friends and family, we have to upload your contacts to our servers."

A very large percentage of our users [have now] opted back in. In [the latest version of Path] we go a step further and we encrypt the whole set of data. Even if we wanted to look at it or we were hacked, it's safe. tr

*Photograph by* TIMOTHY ARCHIBALD


@mike
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personal

Tesla Motors will deliver its first batch of Model S sedans this July. Here, one is guided past a series of robotic spray-paint guns.

PHOTO ESSAY

# Building Tesla

Just as Tesla's cars don't feel like anything from Detroit, the California factory that produces the company's upcoming Model S electric sedan is inspired as much by Tesla's high-tech neighbors in Silicon Valley as by a typical auto plant. In particular, Tesla is obsessive about taking care of details itself—whether it's forming the cars' bodies from scratch or making tools for the robots that build the vehicles.

*By* TIMOTHY MAHER *Photographs by* JOHN STOCKLIN

Aside from the battery cell, Tesla builds almost every part of the Model S at its plant in Fremont, California. A computerized milling machine (below) uses various heads (left) to create tools for the robots (opposite page) that manipulate parts and assemble the cars. Doing such things in-house means better quality control, says Gilbert Passin, Tesla's vice president of manufacturing.


BSL-050TL3
LEFT HAND
KUKA
TESLA


002
06
CAUTION

The battery cell for the Model S is ready to be installed (opposite page). Passin says Tesla designed the car so that the battery goes in almost the way one would be put into a laptop: "It basically just plugs into the car." The body of the Model S is constructed mostly from aluminum, which arrives at the factory in the form of a 20,000-pound coil (left).

A finished Model S (below) will start at just under $50,000; fully loaded Signature models will cost about $98,000. Given that price, some doubt that Tesla's approach, cool or not, is viable in the long term. "Look at the [Chevrolet] Volt," says Jay Baron, president of the Center for Automotive Research. "That's not selling, and that's at $40,000. I would see the future as being very challenging for Tesla." Passin sounds confident nonetheless: "Not one day goes by when [Tesla cofounder] Elon Musk doesn't remind me—as if I would forget—that this factory is capable of making half a million vehicles a year. There's no doubt in my mind that this factory is going to be full, sooner rather than later."

technology review

# 10

# EMERGING TECHNOLOGIES



The TR10 represents the 10 most important technological milestones reached in the last 12 months. To compile the list, *Technology Review* selects the technologies that we believe will have the greatest impact on the shape of innovation in years to come. This impact can take very different forms: one technology points toward a method of discovering better battery materials for mobile devices and electric vehicles; another offers a new way for entrepreneurs to fund the commercialization of emerging technologies. But in all cases, these are breakthroughs with the potential to transform the world.

*—The Editors*

10

# Egg Stem Cells

## A recent discovery could increase older women's chances of having babies.

Jonathan Tilly may have discovered a way to slow the ticking of women's biological clocks. In a paper published in March, the Harvard University reproductive biologist and his colleagues reported that women carry egg stem cells in their ovaries into adulthood—a possible key to extending the age at which a woman might have a baby.

Today, a woman's fertility is limited by her total supply of eggs and by the diminished quality of those eggs as she reaches her 40s. Tilly's work with the stem cells—cells that can differentiate, or develop into other kinds of cells—could address both issues. For one thing, it's possible that these newly discovered cells could be coaxed to develop into new eggs. And even if not, he says, they could be used to rejuvenate an older woman's existing eggs.

Tilly first found egg stem cells in mice in 2004. Once he identified egg stem cells in ovarian tissue from adult women, he isolated the cells and injected them into human ovary tissue that was then transplanted into mice. There the cells differentiated into human oocytes, the immature egg cells that mature, one at a time, at ovulation. Tilly didn't take these oocytes any further, but he says he has gotten egg stem cells from mice to generate functional mouse eggs that were fertilized and exhibited early embryonic development.

The research is still a long way from creating a crying human newborn. Nevertheless, the paper "changes what we understand" about fertility, says Tilly, who also directs a center for reproductive biology at Massachusetts General Hospital. Though some of Tilly's peers remain dubious that the cells he's found in women's ovarian tissue are actually stem cells or could become functional egg cells, many find the research provocative. "I think this is a very intriguing leap," says Elizabeth McGee, an associate professor and head of reproductive endocrinology and infertility at Virginia Commonwealth University. "However, I think there's still a long way to go before this becomes a useful product for women."

Boston-based OvaScience, which is commercializing Tilly's work, hopes it won't be too long. The company's cofounders include venture capitalist Christoph Westphal and Harvard anti-aging researcher David Sinclair, who founded Sirtris Pharmaceuticals and sold it to GlaxoSmithKline for $720 million in 2008. OvaScience has raised $43 million to pursue fertility treatments and other applications for the stem cells.

One of the more tantalizing implications is that this technology could be used to reclaim the youth of an older woman's eggs. Tilly says he can do this by transferring mitochondria—the cell's power source—from the stem-cell-derived cells into the existing eggs. Researchers who tried something similar in the 1990s, with the help of young donors, found that mitochondria from the donors' egg cells could improve the viability of older eggs. But the nearly 30 children who resulted from this work ended up with DNA from two women as well as their father. (It's not clear whether the children suffered any health consequences.) By being her own source for the younger mitochondria, a woman could avoid that potentially dangerous mix of DNA, Tilly says.

David Albertini, director of the Center for Reproductive Sciences at the University of Kansas Medical Center and a member of OvaScience's advisory board, says he "can't wait to get [his] hands on" Tilly's cells for his own egg research. But he says it's too soon to consider implanting them in women before much more testing is done in mice. *—Karen Weintraub*

WHO
**Jonathan Tilly**
OvaScience, Boston

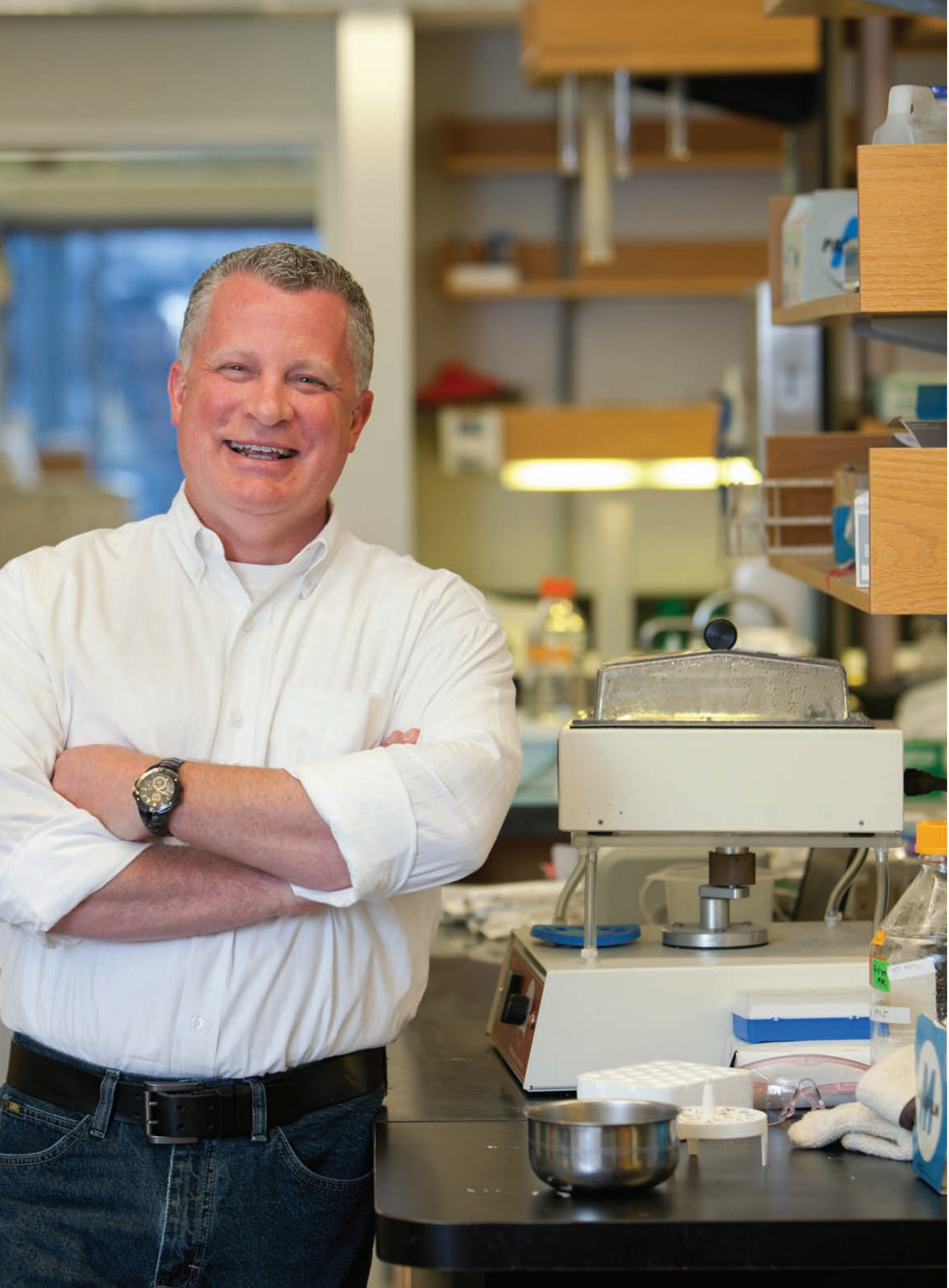
TECHNOLOGY
Stem cells in ovarian tissue could form new eggs or be used to rejuvenate a woman's existing eggs.

OTHER NOTABLE INNOVATORS

**Evelyn Telfer**
University of Edinburgh, Scotland

**David Albertini**
University of Kansas

JOHN SOARES



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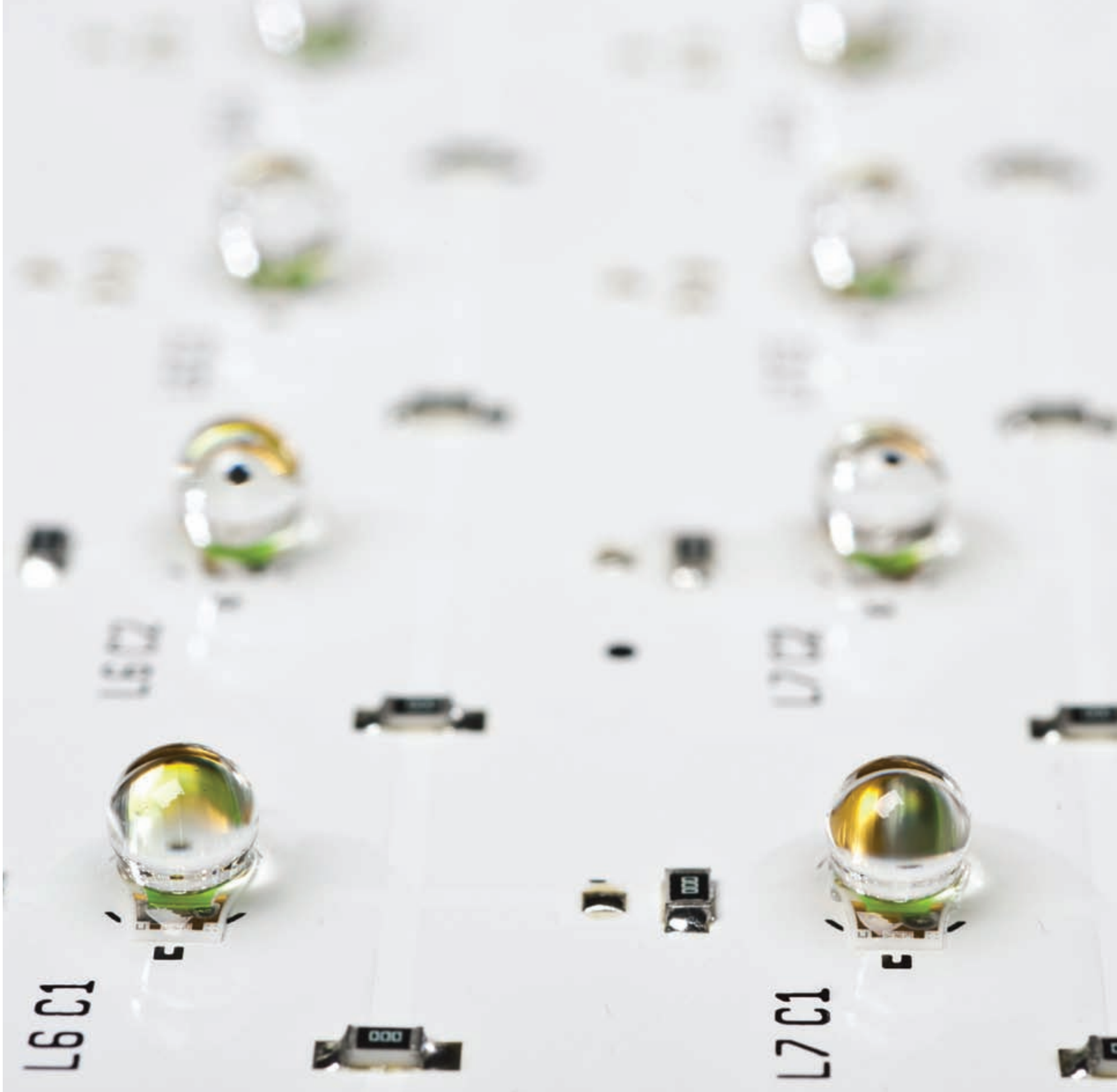


SEMPRIUS

WHO
**Semprius**
Durham,
North Carolina

TECHNOLOGY
Tiny solar cells can convert a high proportion of sunlight into electricity without requiring cooling.

OTHER NOTABLE INNOVATORS
**Alta Devices**
Santa Clara, California
**Solar Junction**
San Jose, California

# Ultra-Efficient Solar

## Under the right circumstances, solar cells from Semprius could produce power more cheaply than fossil fuels.

This past winter, a startup called Semprius set an important record for solar energy: it showed that its solar panels can convert nearly 34 percent of the light that hits them into electricity. Semprius says its technology, once scaled up, is so efficient that in some places, it could soon make electricity cheaply enough to compete with power plants fueled by coal and natural gas.

Because solar installations have many fixed costs, including real estate for the arrays of panels, it is important to maximize the efficiency of each panel in order to bring down the price of solar energy. Companies are trying a variety of ways to do that, including using materials other than silicon, the most common semiconductor in solar panels today.

For example, a startup called Alta Devices *(see the TR50, March/April 2012)* makes flexible sheets of solar cells out of a highly efficient material called gallium arsenide. Semprius also uses gallium arsenide, which is better than silicon at turning light into electricity (the record efficiency measured in a silicon solar panel is about 23 percent). But gallium arsenide is also far more expensive, so Semprius is trying to make up for the cost in several ways.

One is by shrinking its solar cells, the individual light absorbers in a solar panel, to just 600 micrometers wide, 600 micrometers long, and 10 micrometers thick. Its manufacturing process is built on research by cofounder John Rogers, a professor of chemistry and engineering at the University of Illinois, who figured out

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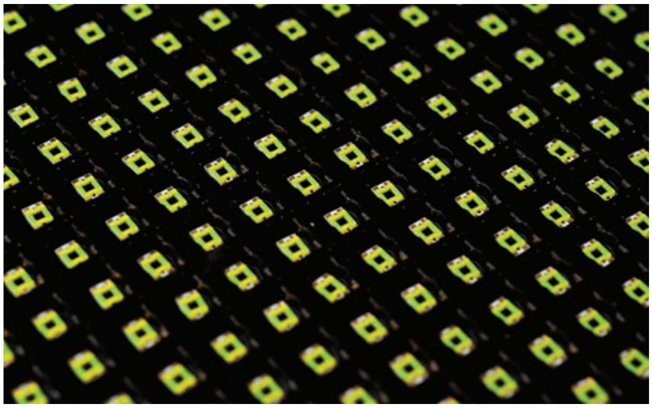

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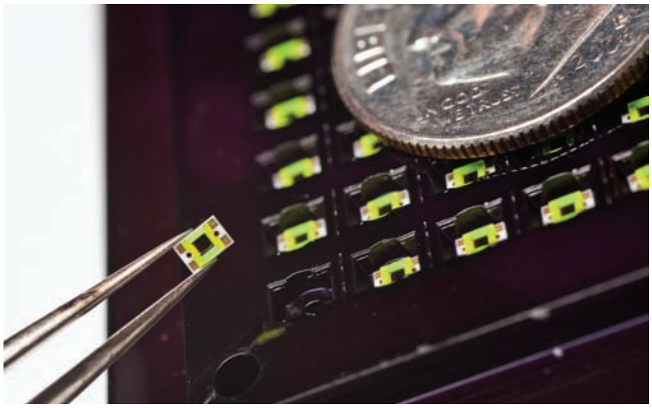

3

1/ Semprius's solar panels use glass lenses to concentrate incoming light, maximizing the power production of tiny photovoltaic cells.

2/ A new mass-production process makes high-efficiency gallium arsenide a more cost-effective photovoltaic material.

3/ The gallium arsenide is the black square on each cell. Using such small amounts of the expensive material keeps costs down.

a way to grow the small cells on a gallium arsenide wafer, lift them off quickly, and then reuse the wafer to make more cells. Once the cells are laid down, Semprius maximizes their power production by putting them under glass lenses that concentrate sunlight about 1,100 times.

Concentrating sunlight on solar panels is not new, but with larger silicon cells, a cooling system typically must be used to conduct away the heat that this generates. Semprius's small cells produce so little heat that they don't require cooling, which further brings down the cost. Scott Burroughs, Semprius's vice president of technology, says utilities that use its system should be able to produce electricity at around eight cents per kilowatt-hour in a few years. That's less than the U.S. average retail price for electricity, which was about 10 cents per kilowatt-hour in 2011, according to the U.S. Energy Information Administration.

Semprius's advantages are tempered by the limitations of using lenses to concentrate light: the system works best when the cells receive direct sunlight under a cloudless sky, and energy production drops significantly under any other conditions. Even so, it could be suitable for large, utility-scale projects in places such as the American Southwest.

First, however, Semprius has to begin mass-producing its panels. The company, which has raised about $44 million from venture capital firms and Siemens (which builds solar power plants), plans this year to open a small factory in North Carolina that can make enough solar panels annually to deliver six megawatts of electricity. The company hopes to expand that to 30 megawatts by the end of 2013, but to do so it must raise an undisclosed amount of money in an atmosphere that is no longer kind to capital-intensive energy startups.

All the while, Semprius will also have to reduce its manufacturing costs fast enough to compete with conventional silicon panels, whose prices fell by more than half in 2011 alone. *—Ucilia Wang*

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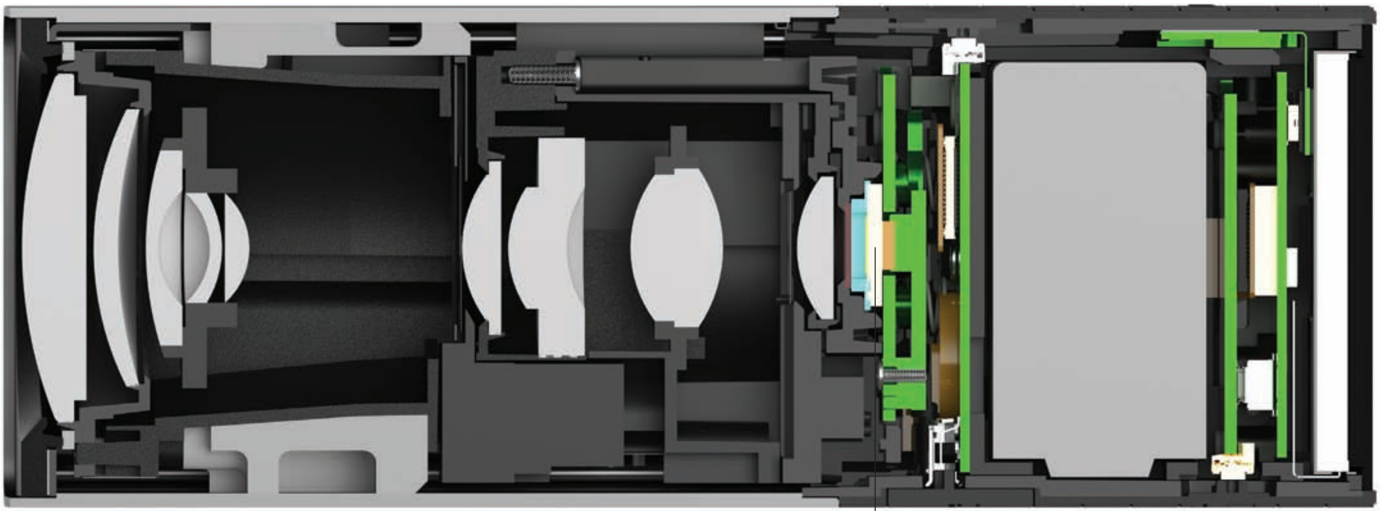

A complex arrangement of lenses captures all incoming light, preserving as much optical data as possible.

A sensor fitted with a microlens array records the color, light, and direction of about 11 million light rays.

A processor converts information from the sensor into a database that can be analyzed to extract images.

WHO

**Lytro**
Mountain View, California

TECHNOLOGY

A camera that lets images be adjusted after the shot.

OTHER NOTABLE INNOVATORS

**Amit Agrawal**
Mitsubishi Electric Research Labs

**Ramesh Raskar**
MIT

# Light-Field Photography

## Lytro reinvented the camera so that it can evolve faster.

This March brought the first major update to camera design since the dawn of cheap digital photography: a camera that lets you adjust the focus of an image after you've taken the picture. It is being sold for $399 and up by Lytro, a startup based in Silicon Valley that plans to use its technology to offer much more than the refocusing trick—options like making 3-D images at home.

All consumer cameras create images using a flat plate—whether chemical film or a digital sensor—to record the position, color, and intensity of the light that comes through a lens. Lytro's camera does all that, but it also records the angle at which rays of light arrive (see graphic). The resulting files aren't images but mini-databases capturing the three-dimensional pattern of light, called a light field, at a particular moment. Software can mine that database to produce many different possible photos and visual effects from one press of the shutter.

Light-field cameras existed before, but they had limited industrial uses and were never cheap enough for consumers. Lytro founder Ren Ng, who

1/ Recording the entire light field entering the camera means that images can be focused after the fact: a user can choose near, far, or any focus in between.

2/ Lytro has wrapped its technology in a consumer-friendly package, making this new form of photography more likely to catch on.

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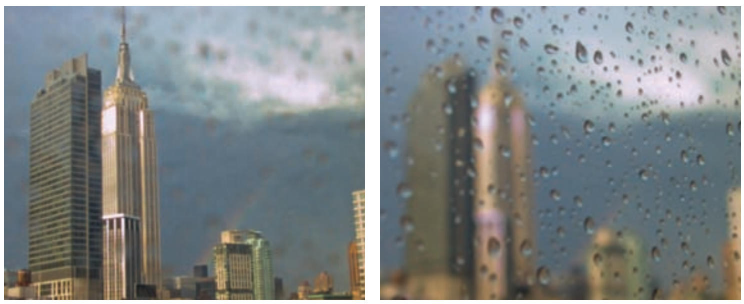


LYTRO

worked on light-field technology for his PhD at Stanford University, made this one affordable by simplifying the design. Instead of using multiple lenses, which made previous light-field cameras expensive and delicate, Ng showed that laying a low-cost plastic film patterned with tiny microlenses on top of a regular digital sensor could enable it to detect the direction of incoming light.

Refocusing images after they are shot is just the beginning of what Lytro's cameras will be able to do. A downloadable software update will soon enable them to capture everything in a photo in sharp focus regardless of its distance from the lens, which is practically impossible with a conventional camera. Another update scheduled for this year will use the data in a Lytro snapshot to create a 3-D image. Ng is also exploring a video camera that could be focused after shots were taken, potentially giving home movies a much-needed boost in production values.

Images from Lytro cameras can be shared on websites and Facebook in a way that allows other people to experiment with changing the focus to explore what the photographer captured. This kind of flexibility is so appealing, Ng says, that "in the future, all cameras will be light-field-based." —*Tom Simonite*

2

Rural Indians are replacing kerosene lamps with cheaper and cleaner LEDs.

# Solar Microgrids

## Village-scale DC grids provide power for lighting and cell phones.

Nearly 400 million Indians, mostly those living in rural communities, lack access to grid power. For many of them, simply charging a cell phone requires a long trip to a town with a recharging kiosk, and their homes are dimly lit by sooty kerosene-fueled lamps.

To change that, Nikhil Jaisinghani and Brian Shaad cofounded Mera Gao Power. Taking advantage of the falling cost of solar panels and LEDs, the company aims to build and operate low-cost solar-powered microgrids that can provide clean light and charge phones. Microgrids distribute electricity in a limited area from a relatively small generation point. While alternative solutions, such as individual solar-powered lanterns, can also provide light and charge phones, the advantage of a microgrid is that the installation cost can be spread across a village. The system can also use more efficient, larger-scale generation and storage systems, lowering operational costs.

Mera Gao's first commercial microgrid was deployed last summer, and eight more villages have been added since; there are plans to expand to another 40 villages this year with the help of a $300,000 grant from the U.S. Agency for International Development. The company has also encouraged others to enter the Indian market for off-grid renewable energy, which the World Resources Institute, a think tank based in Washington, DC, estimates at $2 billion per year.

For a cost of $2,500, a hundred households, in groups of up to 15, can be wired up to two generation hubs, each consisting of a set of solar panels and a battery pack. The grid uses 24-volt DC power

WHO
**Mera Gao Power**
Reusa, India

TECHNOLOGY
Solar-powered microgrids will let rural villagers light their homes and charge cell phones for less money

OTHER NOTABLE INNOVATORS
**The Energy and Resources Institute**
New Delhi, India

**Husk Power Systems**
Bihar, India

**University of California, Davis**

10

throughout, which permits the use of aluminum wiring rather than the more expensive copper wiring required for higher-voltage AC distribution systems. The village is carefully mapped before installation to ensure the most efficient arrangement of distribution lines. (Circuit breakers will trip if a freeloader tries to tap in.) "This mapping and design is our biggest innovation," Jaisinghani says.

Each household gets 0.2 amps for seven hours a night—enough to power two LED lights and a mobile-phone charging point—for a prepaid monthly fee of 100 rupees ($2); kerosene and phone charging generally cost 100 to 150 rupees a month.

Jaisinghani says Mera Gao's microgrid is not a replacement for grid power, but it's what people want and can pay for right now. Currently the technology supports only lighting and phone charging, but the company is exploring ideas such as community entertainment centers where the costs of television, radio, cooling fans, and information services are spread across a group of homes rather than being paid by a single user.

—*Seema Singh*

A typical installation uses two banks of solar panels, located on different rooftops.

# 3-D Transistors

## Intel creates faster and more energy-efficient processors.

In an effort to keep squeezing more components onto silicon chips, Intel has begun mass-producing processors based on 3-D transistors. The move not only extends the life of Moore's Law (the prediction that the number of transistors per chip will double roughly every two years) but could help significantly increase the energy efficiency and speed of processors.

The on-and-off flow of current in conventional chips is controlled by an electric field generated by a so-called gate that sits on top of a wide, shallow conducting channel embedded in a silicon substrate. With the 3-D transistors, that current-carrying channel has been flipped upright, rising off the surface of the chip. The channel material can thus be in contact with the gate on both its sides and its top, leaving little of the channel exposed to interference from stray charges in the substrate below. In earlier transistors, these charges interfered with the gate's ability to block current, resulting in a constant flow of leakage current.

With virtually no leakage current, a transistor can switch on and off more cleanly and quickly, and it can be run at lower power, since designers don't have to worry that leakage current could be mistaken for an "on" signal.

Intel claims the new transistors can switch up to 37 percent faster than its previous transistors or consume as little as half as much power. Faster switching means faster chips. In addition, because of their smaller footprint, the transistors can be packed closer together. Signals thus take less time to travel between them, further speeding up the chip.

The first processors based on the technology will shortly appear in laptops. But the electronics industry is especially excited by the prospect of conserving power in handheld devices. That means designers can upgrade the performance of a device without requiring bulkier batteries, or reduce battery size without lowering performance. "Ten years ago everyone only cared about making chips faster," says Mark Bohr, who heads process technology at Intel. "Today low-power operation is much more important." He adds that the power savings and performance gains will be magnified in handheld devices because the smaller transistors will make it possible for a single chip to handle functions such memory, broadband communications, and GPS, each of which used to require its own chip. With fewer chips and smaller batteries, gadgets will be able to do more in tinier packages.

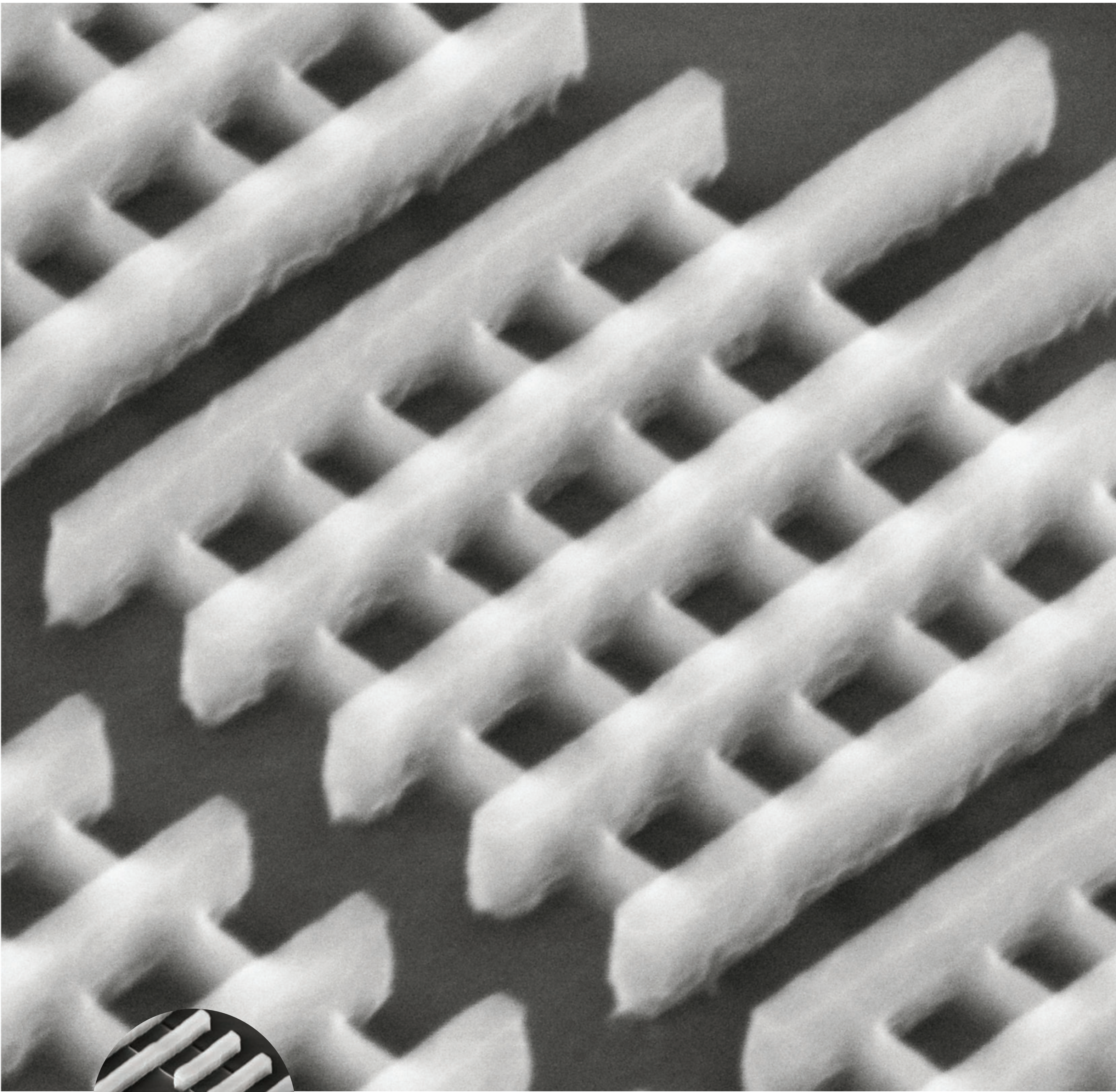
The new transistor design leaves room for enough further improvement to see the industry through the next five years. Intel's previous chips could pack in 4.87 million transistors per square millimeter; the new chips have 8.75 million, and by 2017, about 30 million transistors per square millimeter should be possible. "This buys silicon another few generations," says Bohr. —*David H. Freedman*

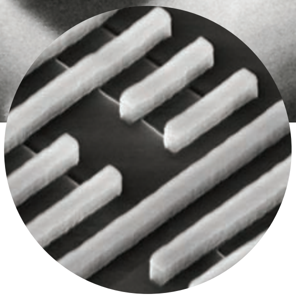
WHO
**Intel**
Santa Clara, California

TECHNOLOGY
Transistors that use less electricity and can be packed closer together will result in smaller, more powerful mobile devices.

OTHER NOTABLE INNOVATORS
**IBM**
Armonk, New York
**Samsung**
Seoul, South Korea
**GlobalFoundries**
Milpitas, California

THIS PAGE AND PREVIOUS: ANNA DA COSTA; OPPOSITE: INTEL





The new transistors (above) have vertical current-carrying channels. In older designs (inset), the channels lie flat under the gates.

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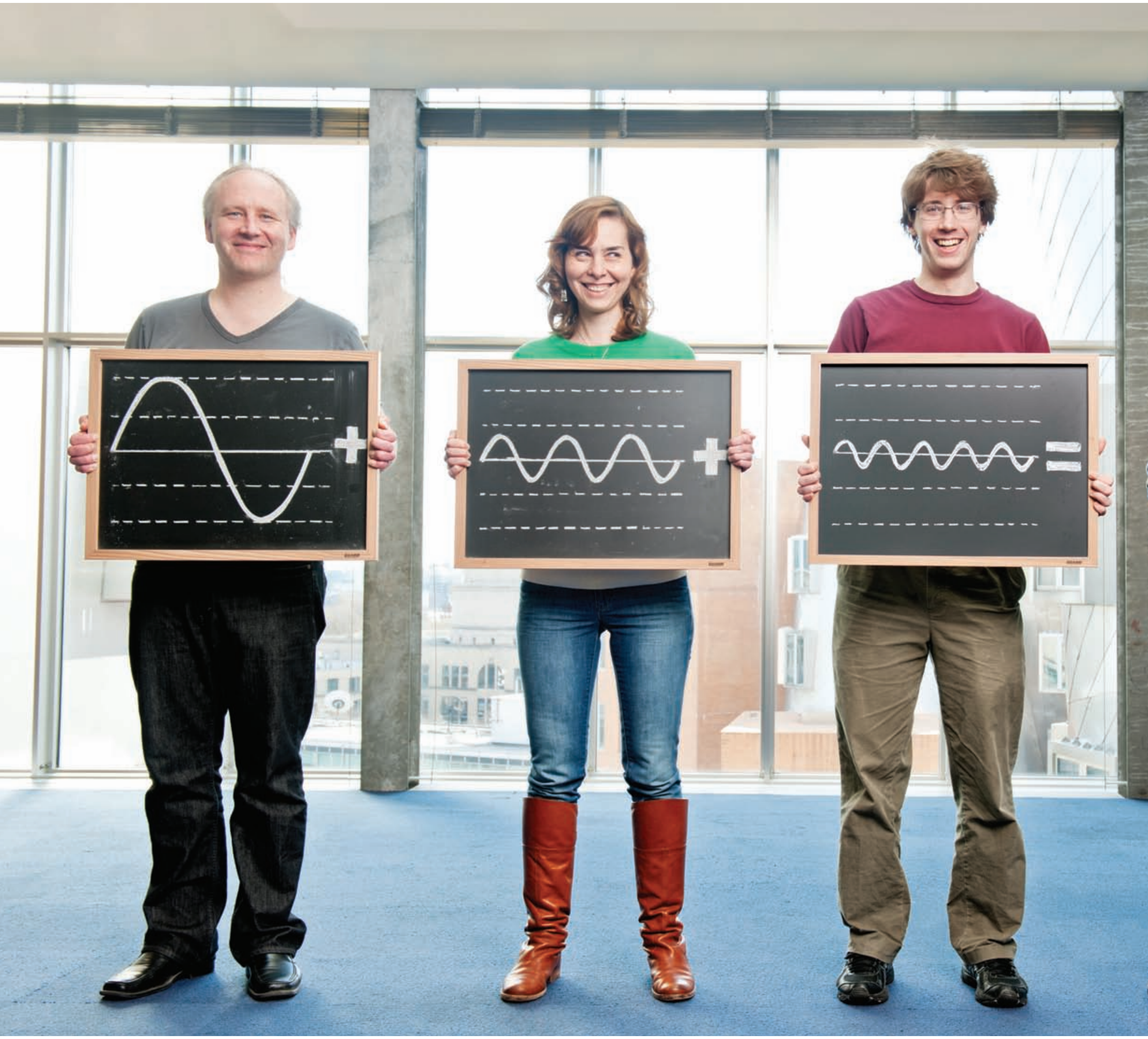

WEBB CHAPPELL

Piotr Indyk, Dina Katabi, Eric Price, and Haitham Hassanieh (left to right) have created a faster way to break down complex signals into combinations of simple waves for processing.

WHO
**MIT**
Cambridge, Massachusetts

TECHNOLOGY
A new algorithm for processing streams of data will lead to better multimedia devices.

OTHER NOTABLE INNOVATORS

**Richard Baraniuk**
Rice University, Houston, Texas

**Anna Gilbert and Martin Strauss**
University of Michigan

**Joel A. Tropp**
Caltech, Pasadena, California

**Mark Iwen**
Duke University, Durham, North Carolina

# A Faster Fourier Transform

## A mathematical upgrade promises a speedier digital world.

In January, four MIT researchers showed off a replacement for one of the most important algorithms in computer science. Dina Katabi, Haitham Hassanieh, Piotr Indyk, and Eric Price have created a faster way to perform the Fourier transform, a mathematical technique for processing streams of data that underlies the operation of things such as digital medical imaging, Wi-Fi routers, and 4G cellular networks.

The principle of the Fourier transform, which dates back to the 19th century, is that any signal, such as a sound recording, can be represented as the sum of a collection of sine and cosine waves with different frequencies and amplitudes. This collection of waves can then be manipulated with relative ease—for example, allowing a recording to be compressed or noise to be suppressed. In the mid-1960s, a computer-friendly algorithm called the fast Fourier transform (FFT) was developed. Anyone who's marveled at the tiny size of an MP3 file compared with the same recording in an uncompressed form has seen the power of the FFT at work.

With the new algorithm, called the sparse Fourier transform (SFT), streams of data can be processed 10 to 100 times faster than was possible with the FFT. The speedup can occur because the information we care about most has a great deal of structure: music is not random noise. These meaningful signals typically have only a fraction of the possible values that a signal could take; the technical term for this is that the information is "sparse." Because the SFT algorithm isn't intended to work with all possible streams of data, it can take certain shortcuts not otherwise available. In theory, an algorithm that can handle only sparse signals is much more limited than the FFT. But "sparsity is everywhere," points out coinventor Katabi, a professor of electrical engineering and computer science. "It's in nature; it's in video signals; it's in audio signals."

A faster transform means that less computer power is required to process a given amount of information—a boon to energy-conscious mobile multimedia devices such as smart phones. Or with the same amount of power, engineers can contemplate doing things that the computing demands of the original FFT made impractical. For example, Internet backbones and routers today can actually read or process only a tiny trickle of the river of bits they pass between them. The SFT could allow researchers to study the flow of this traffic in much greater detail as bits shoot by billions of times a second. *—Mark Anderson*

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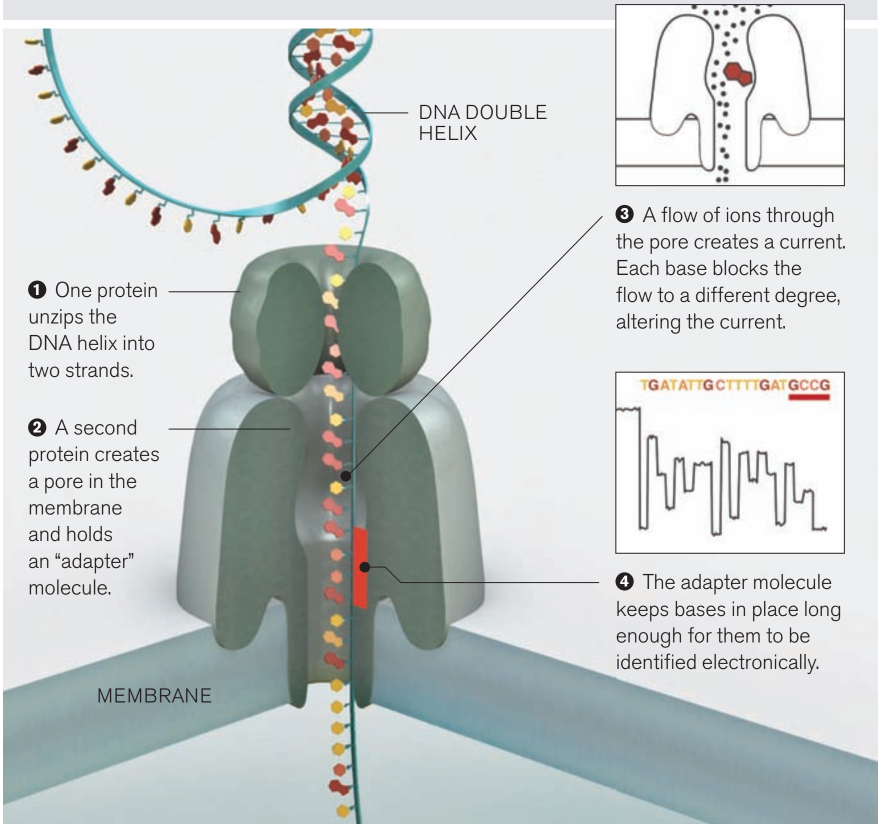
DNA can be sequenced by threading it through a microscopic pore in a membrane. Bases are identified by the way they affect ions flowing through the pore from one side of the membrane to the other.




# Nanopore Sequencing

## Simple and direct analysis of DNA will make genetic testing routine in more situations.

Oxford Nanopore has demonstrated commercial machines that read DNA bases directly. The technology offers a way to make genome sequencing faster, cheaper, and potentially convenient enough to let doctors use sequencing as routinely as they order an MRI or a blood cell count, ushering in an era of personalized medicine.

The company's devices, which eliminate the need to amplify DNA or use expensive reagents, work by passing a single strand of DNA through a protein pore created in a membrane. An electric current flows through the pore; different DNA bases disrupt the current in different ways, letting the machine electronically read out the sequence.

Rival sequencing technologies have gotten faster and cheaper in recent years as well. But most of them either use fluorescent reagents to identify bases or require chopping up the DNA molecule and amplifying the fragments. Nanopore's technology is simpler, and it avoids errors that can creep in during these steps.

Being able to read DNA molecules directly also means that longer segments of a genome can be read at a time. This makes it easier for researchers to see large-scale patterns such as translocations, in which chunks of DNA are displaced from one part of the genome to another, and copy number variations, in which DNA sequences are repeated several times or more. (Translocations are thought to underlie various forms of cancer and other diseases, while copy number variations are linked to a range of neurological and developmental disorders.)

The company reports reading a stretch of DNA roughly 48,000 bases long. "That's by far the longest piece of DNA that anyone's claimed to read," says Jeffery Schloss, program director for technology development at the National Human Genome Research Institute.

Oxford Nanopore's new product line (which will begin shipping later this year) will include a miniaturized portable device, roughly the size of two decks of cards, that can plug directly into a computer's USB port and is capable of sequencing small volumes of DNA. A larger desktop machine can handle larger volumes; clusters of these machines will be used for sequencing whole genomes. Although the company has not yet announced pricing for the desktop machine, the portable version could cost less than $900. This device will make it easier to read limited amounts of DNA in a host of settings, including remote clinics or food processing plants, where inspectors could monitor for contamination by dangerous strains of bacteria.

—*Amanda Schaffer*

WHO
**Oxford Nanopore**
Oxford, U.K.

TECHNOLOGY
Reading long DNA strands electronically could make genome sequencing a routine medical procedure.

OTHER NOTABLE INNOVATORS
**Complete Genomics**
Mountain View, California

**Life Technologies**
Grand Island, New York

**Illumina**
San Diego, California

JOHN MACNEILL

SIEMENS



# Neighborhoods powered by parks.

**An underground substation built by Siemens helps make Anaheim a city worth building a future in.**

As the residents of Anaheim, California, walk their dogs in the morning, few realize there's a substation right under their feet distributing power throughout their neighborhood.

The station under Roosevelt Park delivers much-needed power to 25,000 people. It's the first underground substation in America, a feat made possible by an advanced design that makes it 70 percent smaller than traditional substations.

It seems like such a simple idea. But by putting the substation beneath the ground instead of above it, Siemens helped make life in Anaheim a little bit better.

Today, cities across the nation face countless choices about how to generate, distribute, and use electricity. Those choices call for unconventional thinking — because that's the kind of thinking that leads to truly lasting answers.

Somewhere in America, our team of more than 60,000 employees spends every day creating answers that will last for years to come.

**siemens.com/answers**

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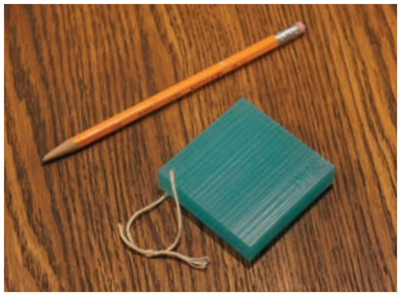


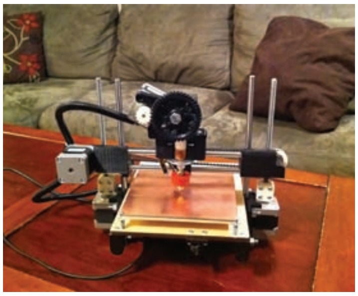


Entrepreneurs can post videos and pictures on Kickstarter to attract pledges for projects. Some success stories (clockwise from top left):

Elevation iPhone dock
**$1,460,000**

Double Fine Adventure (video game)
**$3,330,000**

Twine Wi-Fi sensors
**$557,000**

CloudFTP wireless thumb drive hub
**$262,000**

PrintrBot 3-D printer
**$831,000**

*The Order of the Stick* (comic book)
**$1,250,000**

# Crowdfunding

Kickstarter is funding the commercialization of new technologies.

WHO
**Kickstarter**
New York City

TECHNOLOGY
An alternative to angel or venture capital investment helps fund tech startups.

OTHER NOTABLE INNOVATORS
**Indiegogo**
San Francisco
**Crowdcube**
Exeter, U.K.
**Seedrs**
London
**WeFunder**
Cambridge, Massachusetts
**GrowVC**
Hong Kong

Kickstarter, a New York City–based website originally founded to support creative projects, has become a force in financing technology startups. Entrepreneurs have used the site to raise hundreds of thousands of dollars at a time to develop and produce products, including a networked home sensing system and a kit that prints three-dimensional objects *(see Hack, p. 86)*.

This crowdfunding model offers an alternative to traditional means of raising startup funds for some types of businesses, such as Web or design firms. Startups keep their equity, maintain full control over strategy, and gain a committed community of early adopters to boot.

While most projects ask for relatively small amounts, several have exceeded the $1 million mark. Most notably, Double Fine Productions raised over $3 million to develop a video game. That's well beyond the typical angel stake, which generally tops out at $600,000, and into the realm of the typical venture capital infusion.

Overall, Kickstarter users pledged nearly $99.3 million for projects last year—an amount roughly equivalent to 10 percent of all seed investment in the United States, which PricewaterhouseCoopers estimates at $920 million.

People seeking to raise money for a project set a funding target and solicit pledges. If a project fails to reach its target (as happened to about 54 percent of them in 2011), supporters pay nothing. For projects that do hit their target, donors receive a variety of rewards, including thank-you notes, products, or even elaborate packages that might include a visit to the creators' place of work. Kickstarter, which was launched in 2009 by Yancey Strickler, Charles Adler, and Perry Chen, takes a 5 percent cut. Since the launch, the site has distributed over $150 million.

Kickstarter's role could begin to shift with the end of the U.S. ban on private companies' selling equity to small investors, which was lifted in April. Says Paul Kedrosky, a senior fellow at the Kauffman Foundation who focuses on risk capital: "If crowdfunding sites start offering equity shares, it will make a few dozen VC firms disappear."

*—Ted Greenwald*

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# High-Speed Materials Discovery

## A new way to identify battery materials suitable for mass production could revolutionize energy storage.

Electric cars could travel farther, and smart phones could have more powerful processors and better, brighter screens, thanks to batteries based on new materials being developed by San Diego–based Wildcat Discovery Technologies.

The company is accelerating the identification of valuable energy storage materials by testing thousands of substances at a time. In March of last year, it announced a lithium cobalt phosphate cathode that boosts energy density by nearly a third over current cathodes in popular lithium-ion phosphate batteries. The company also unveiled an electrolyte additive that allows batteries to work more reliably at higher voltages.

Choosing the optimal materials for batteries is a particularly tricky problem. The devices have three principal components: an anode, a cathode, and an electrolyte. Not only can each be formed from almost any blend of a huge number of compounds, but the three components have to work well together. That leaves many millions of promising combinations to explore.

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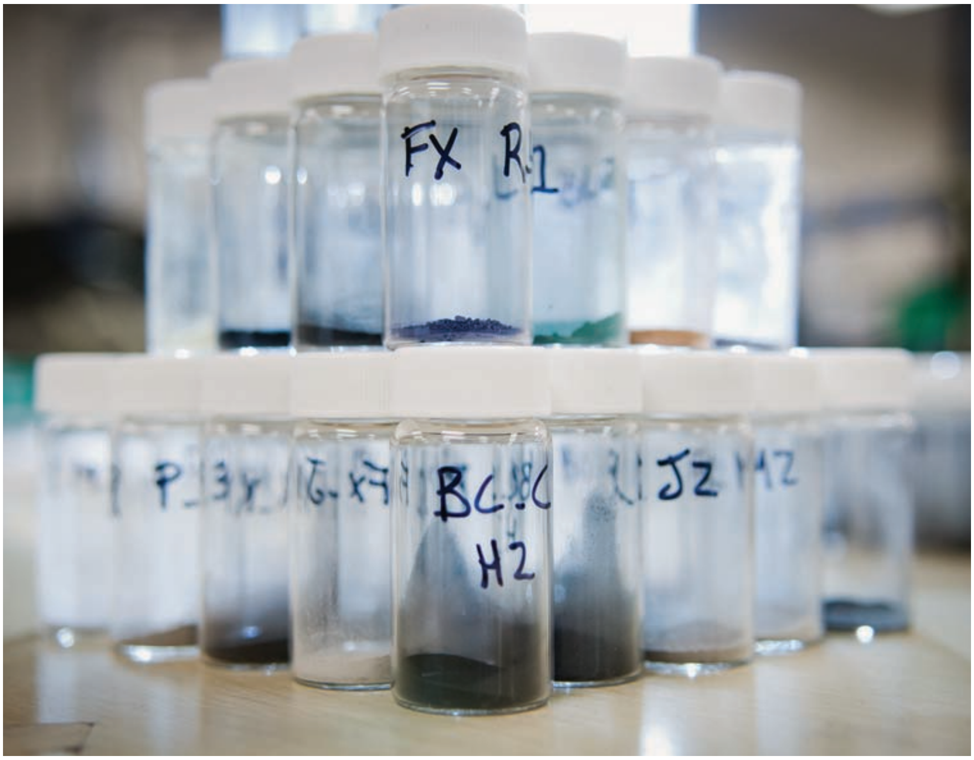



2

3


1/ Wildcat starts with a wide range of precursor materials that may have potential for energy storage and other applications.

2/ Here, some precursor materials have been refined into powder suitable for making battery electrodes.

3/ Cathodes, anodes, and electrolytes are assembled into small working batteries, which are tested by the thousand in this tower. Testing materials together allows dud combinations to be eliminated quickly.

10

To process so many samples, Wildcat relies heavily on automation. This assay machine weighs and records vials of materials.

WHO

**Wildcat Discovery Technologies**
San Diego, California

TECHNOLOGY

High-throughput testing speeds the discovery of new battery materials.

OTHER NOTABLE INNOVATORS

**Envia Systems**
Newark, California

**Halotechnics**
Emeryville, California

**Siluria**
San Francisco

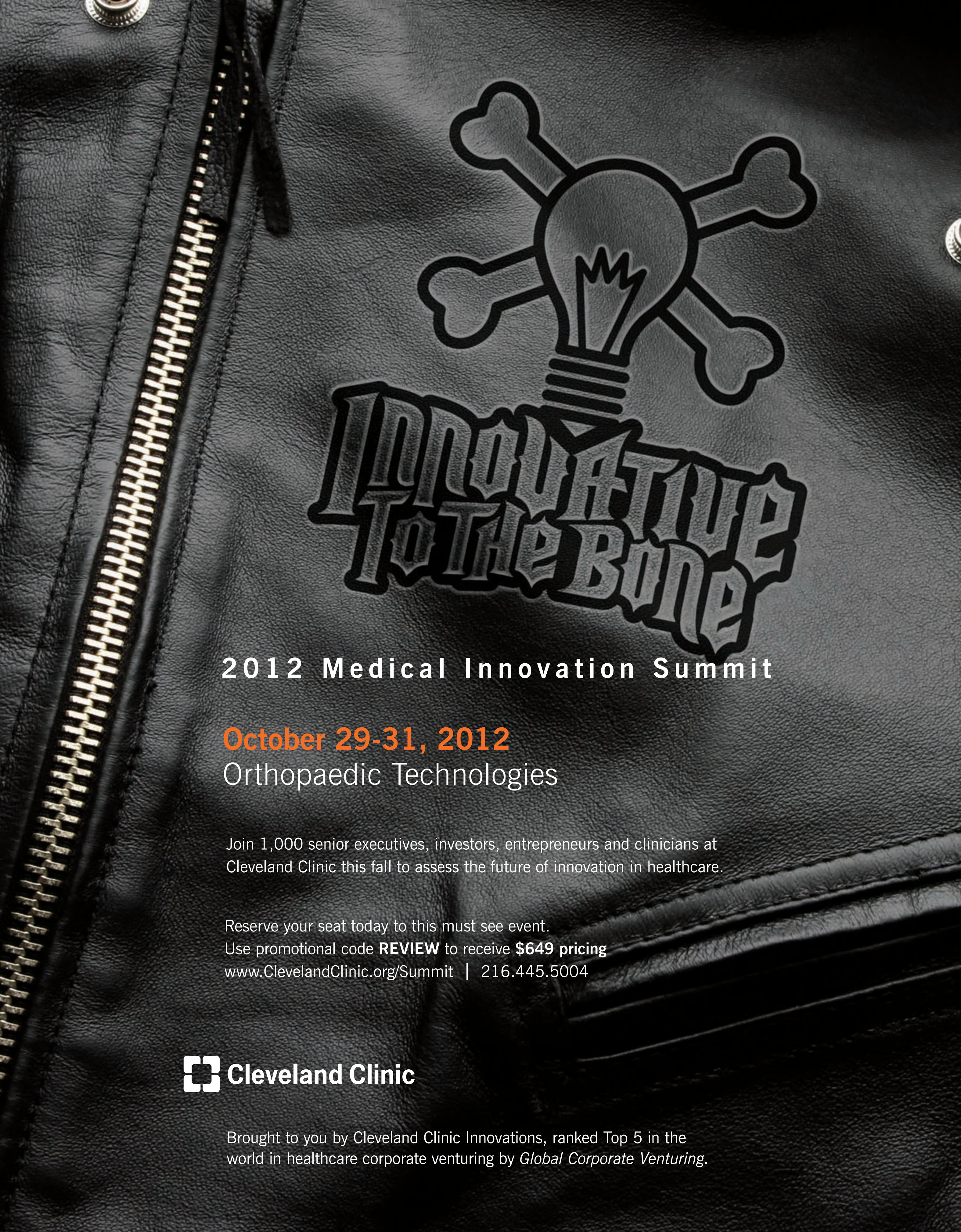
To hunt down winning combinations, Wildcat has adopted a strategy originally developed by drug discovery labs: high-throughput combinatorial chemistry. Instead of testing one material at a time, Wildcat methodically runs through thousands of tests in parallel, synthesizing and testing some 3,000 new material combinations a week. "We've got materials in the pipeline that could triple energy density," says CEO Mark Gresser.

Others have tried the combinatorial technique to find new battery materials, but they've run into a stumbling block. The easy way to test thousands of materials is to deposit a sample of each one in a thin film atop a substrate. This approach did allow previous researchers to turn up promising materials for battery components—but then candidates would typically prove unsuited to cost-effective large-scale production processes.

To avoid that time-wasting detour, Wildcat found ways to produce samples using miniaturized versions of large-scale production techniques. In effect, the candidate materials are being tested for ease of manufacturing at the same time as they're being tested for performance. Wildcat also tests the materials wired together as actual batteries, and in a variety of potential operating conditions. "There are a lot of variables that affect battery performance, including temperature and voltage, and we examine all of them," says Gresser. The result is that a material that performs well in a Wildcat test bed will probably perform well in field tests.

If Wildcat is successful, its efforts could lead to batteries that are smaller or more powerful than their present-day counterparts—improvements that will appeal to the makers of smart phones and electric vehicles alike. *—David H. Freedman*

THIS PAGE AND PREVIOUS SPREAD: FRANK ROGOZIENSKI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# Facebook's Timeline

## The social-networking company is collecting and analyzing consumer data on an unprecedented scale.

Facebook recently introduced its Timeline interface to its 850 million monthly active users. The interface is designed to make it easy to navigate much of the immense amount of information that the social network has gathered about each of its users—and to prompt them to add and share even more in a way that's easy to analyze.

Facebook's motivation is to better target the advertisements that are responsible for 85 percent of its revenue. In part, successful targeting is a numbers game. If reported trends have held steady, Facebook's data warehouse was adding 625,000 terabytes of compressed data daily by last January. Timeline's new features are bound to boost that number dramatically, potentially providing Facebook with more personal data than any other ad seller online can access.

In the past, much of the data that users contributed to Facebook was in the form of unstructured status updates. The addition of a "Like" button, and the ability to link that button to third-party websites *(see "TR10: Social Indexing," May/June 2011)*, provided somewhat more fine-grained information that could be used for targeting ads. Timeline goes well beyond that, prompting users to add an extensive array of metadata to their updates, which makes mining value much easier. And by design, it encourages users to revisit and add more information to old updates, or retroactively add completely new biographical information.

One way Timeline gets users to add marketable meaning is by asking them to categorize their updates under a broad collection of "Life Events," which includes tags for actions like buying a home or vehicle. A user who notes a vehicle purchase is prompted to specify details such as the type, make, and model year of the car, along with when and where the purchase was made and whom the user was with at the time. Connecting the dots, Facebook may determine the gender, income bracket, educational level, and profession of the kind of person likely to buy a specific car.

This growing trove of data is a bonanza to marketers, but it's also a challenge for Facebook, which must keep up with the flood of bits. Approximately 10 percent of Facebook's revenue is devoted to R&D, including efforts to improve the speed, efficiency, and scalability of its infrastructure. If previous spending patterns hold true, much of the company's 2012 capital-expense allocation—more than $1.6 billion—is likely to be devoted to servers and storage devices.

Timeline is making real the concept of the "permanent record," in the form of a computer-assisted autobiography—a searchable multimedia diary of our lives that hovers in the cloud. But it may also have an unintended effect of calling users' attention to just how much Facebook knows about them. Normally, "when people share information about themselves, they see a snapshot," says Deirdre Mulligan, a professor at the UC Berkeley School of Information. "When people see Timeline, they become aware that all those bits and pieces are more than the sum of the parts. They suddenly understand the bigness of their own data."

*—Ted Greenwald*

WHO
**Facebook**
Menlo Park, California

TECHNOLOGY
Structuring vast amounts of user-generated data will benefit advertisers and help users explore their digital autobiographies.

OTHER NOTABLE INNOVATORS
**Bluefin Labs**
Cambridge, Massachusetts

**Microsoft Research**
Seattle

**DataSift**
San Francisco

**COMPLEX RELATIONSHIPS**

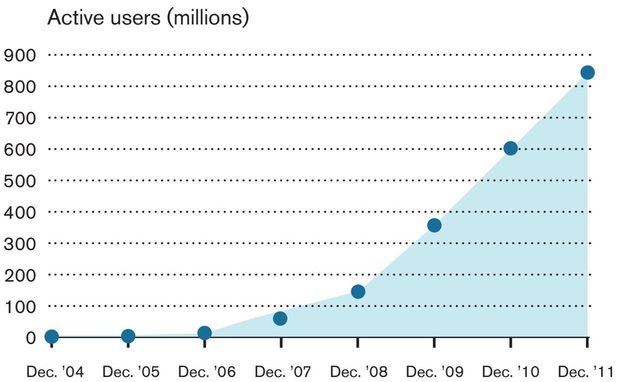
**2.7 billion**

Number of new "likes" and comments daily

**100+ billion**

Number of friend connections as of December 31, 2011

**BOOMING USER BASE**



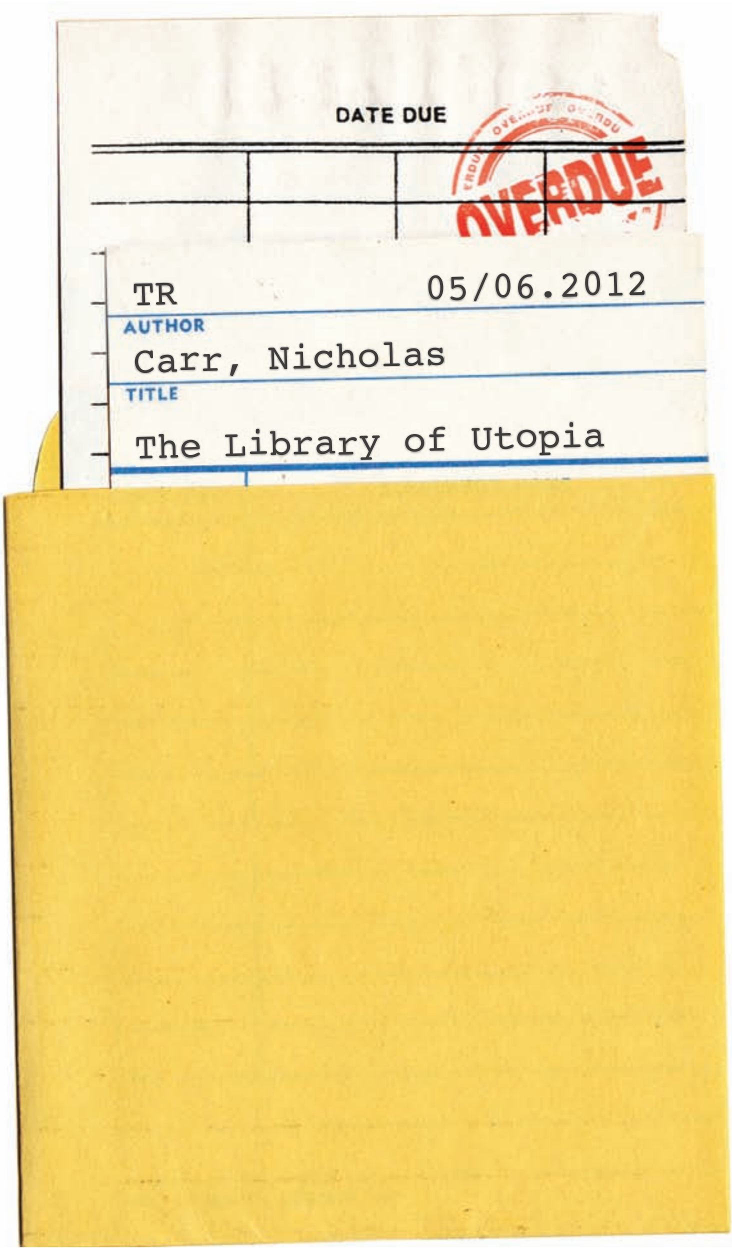

**DATA GALORE**

**126 MB**

Volume of photo and video data per user

**In total, 100 petabytes of photos and video are stored.**

That's the equivalent of up to **several hundred photos** per user.


DATE DUE
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AUTHOR
Carr, Nicholas
TITLE
The Library of Utopia

IN HIS 1938 BOOK *WORLD BRAIN*, H. G. WELLS IMAGINED A TIME—NOT VERY DISTANT, HE BELIEVED—WHEN EVERY PERSON ON THE PLANET WOULD HAVE EASY ACCESS TO "ALL THAT IS THOUGHT AND KNOWN."

The 1930s were a decade of rapid advances in microphotography, and Wells assumed that microfilm would be the technology to make the corpus of human knowledge universally available.

"The time is close at hand," he wrote, "when any student, in any part of the world, will be able to sit with his projector in his own study at his or her convenience to examine *any* book, *any* document, in an exact replica."

Wells's optimism was misplaced. The Second World War put idealistic ventures on hold, and after peace was restored, technical constraints made his plan unworkable. Though microfilm would remain an important medium for storing and preserving documents, it proved too unwieldy, too fragile, and too expensive to serve as the basis for a broad system of knowledge transmission. But Wells's idea is still alive. Today, 75 years later, the prospect of creating a public repository of every book ever published—what the Princeton philosopher Peter Singer calls "the library of utopia"—seems well within our grasp. With the Internet, we have an information system that can store and transmit documents efficiently and cheaply, delivering them on demand to anyone with a computer or a smart phone. All that remains to be done is to digitize the more than 100 million books that have appeared since Gutenberg invented movable type, index their contents, add some descriptive metadata, and put them online with tools for viewing and searching.

It sounds straightforward. And if it were just a matter of moving bits and bytes around, a universal online library might already exist. Google, after all, has

*Google's ambitious book-scanning program is foundering in the courts. Now a Harvard-led group is launching its own sweeping effort to put our literary heritage online. Will the Ivy League succeed where Silicon Valley failed?*

been working on the challenge for 10 years. But the search giant's book program has foundered; it is mired in a legal swamp. Now another momentous project to build a universal library is taking shape. It springs not from Silicon Valley but from Harvard University. The Digital Public Library of America—the DPLA—has big goals, big names, and big contributors. And yet for all the project's strengths, its success is far from assured. Like Google before it, the DPLA is learning that the major problem with constructing a universal library nowadays has little to do with technology. It's the thorny tangle of legal, commercial, and political issues that surrounds the publishing business. Internet or not, the world may still not be ready for the library of utopia.

*Google had the smarts and the money to scan millions of books into its database, but the major problem with constructing a universal library has little to do with technology.*

## Google's Travails

Larry Page isn't known for his literary sensibility, but he does like to think big. In 2002, the Google cofounder decided that it was time for his young company to scan all the world's books into its database. If printed texts weren't brought online, he feared, Google would never fulfill its mission of making the world's information "universally accessible and useful." After doing some book-scanning tests in his office—he manned the camera while Marissa Mayer, then a product manager, turned pages to the beat of a metronome—he concluded that Google had the smarts and the money to get the job done. He set a team of engineers and programmers to work. In a matter of months, they had invented an ingenious scanning device that used a stereoscopic infrared camera to correct for the bowing of pages that occurs when a book is opened. The new scanner made it possible to digitize books rapidly without cutting off their spines or otherwise damaging them. The team also wrote character recognition software that could decipher unusual fonts and other textual oddities in more than 400 languages.

In 2004, Page and his colleagues went public with their project, which they would later name Google Book Search—a reminder that the company, at least originally, thought of the service essentially as an extension of its search engine. Five of the world's largest research libraries, including the New York Public Library and the libraries of Oxford and Harvard, signed on as partners. They agreed to let Google digitize books from their collections in return for copies of the images. The company went on a scanning binge, making digital replicas of millions of volumes. It didn't always restrict itself to books in the public domain; it scanned ones still under copyright, too. That's when the trouble started. The Authors Guild and the Association of American Publishers sued Google, claiming that copying entire books, even with the intent of showing only a few lines of text in search results, constituted "massive" copyright infringement.

Google then made a fateful choice. Instead of going to trial and defending Book Search on grounds that it amounted to "fair use" of copyright-protected material—a case that some legal scholars believe it might have won—it negotiated a sweeping settlement with its adversaries. In 2008, the company agreed to pay large sums to authors and publishers in return for permission to develop a commercial database of books. Under the terms of the deal, Google would be able to sell subscriptions to the database to libraries and other institutions while also using the service as a means for selling e-books and displaying advertisements.

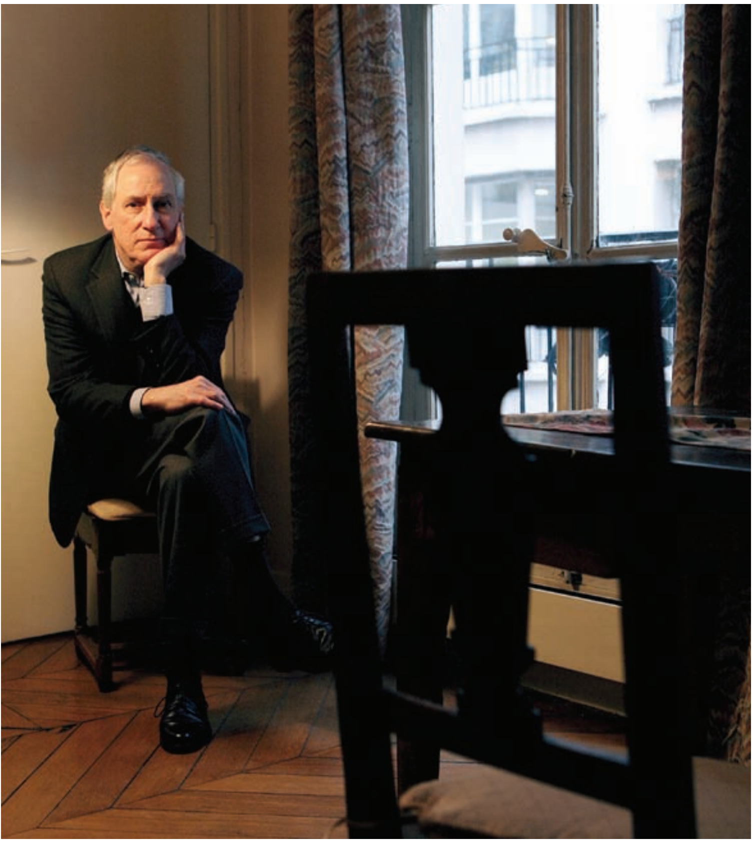
That only deepened the controversy. Librarians and academics lined up to oppose the deal. Many authors asked that their works be exempted from it. The U.S. Justice Department raised antitrust concerns. Foreign publishers howled. Last year, after a final round of legal maneuvering, federal district judge Denny Chin rejected the settlement, saying it "would simply go too far." Listing a variety of objections, he argued that the pact would not only "grant Google significant rights to exploit entire books, without permission of the copyright owners," but also reward the company for its "wholesale copying of copyrighted works" in the past. The company now finds itself nearly back at square one, with the original lawsuits slated to go to trial this summer. Facing new competitive threats from Facebook and other social networks, Google may no longer see Book Search as a priority. A decade after it began, Page's bold project has stalled.

## Seeking Enlightenment

If you were looking for Larry Page's opposite, you would be hard pressed to find a better candidate than Robert Darnton. A distinguished historian and prize-winning author, a former Rhodes scholar and MacArthur fellow, a Chevalier in France's Légion d'Honneur, and a 2011 recipient of the National Humanities Medal, the 72-year-old Darnton is everything that Page is not: eloquent, diplomatic, and embedded in the literary establishment. If Page is a bull in a china shop, Darnton is the china shop's proprietor.

But Darnton has one thing in common with Page: an ardent desire to see a universal library established online, a library that would, as he puts it, "make all knowledge available to all citizens." In the 1990s he initiated two groundbreaking projects to digitize scholarly and historical works, and by the end of the decade he was writing erudite essays about the possibilities of electronic books and digital scholarship. In 2007 he was recruited to Harvard and named the director of its library system, giving him a prominent perch for promoting his dream. Although Harvard was one of the original partners in Google's scanning scheme, Darnton soon became the most eminent and influential critic of the Book Search settlement, writing articles and giving lectures in opposition to the deal. His criticism was as withering as it was learned. Google Book Search, he maintained, was "a commercial speculation" that,

PAGE 54 ILLUSTRATION: TECHNOLOGY REVIEW; PHOTO: CALSIDYROSE



Robert Darnton has written that he wants to open up "nearly everything available in the walled-in repositories of human culture."

THIERRY DUDOIT/EXPRESS-REA/REDUX

under the liberal terms of the settlement, seemed fated to grow into "a hegemonic, financially unbeatable, technologically unassailable, and legally invulnerable enterprise that can crush all competition." It would become "a monopoly of a new kind, not of railroads or steel, but of access to information."

Darnton's rhetoric seemed overwrought to some. University of Michigan librarian Paul Courant accused him of spreading "a dystopian fantasy." But Darnton had cause to be concerned. Over the years, he had watched commercial publishers relentlessly ratchet up subscription prices for scholarly journals. Annual renewal fees had soared into the thousands of dollars for many periodicals, squeezing the budgets of research libraries. Darnton feared that Google, operating under the broad commercial protections granted by the settlement, would have the power to charge whatever it wanted for subscriptions to its database. Libraries might end up paying exorbitant sums to gain access to the very volumes they had let Google scan for free. The company's executives, Darnton acknowledged, seemed to be filled with idealism and goodwill, but there was no guarantee that they, or their successors, would not become profit-hungry predators in the future. By allowing "the commercialization of the content of our libraries," he argued, the agreement "would turn the Internet into an instrument for privatizing knowledge that belongs in the public sphere."

If libraries and universities worked together, Darnton argued, with funding from charitable foundations, they could build a true digital public library of America. Darnton's inspiration for the DPLA came not from today's technologists but from the great philosophers of the Enlightenment. As ideas circulated through Europe and across the Atlantic during the 18th century, propelled by the technologies of the printing press and the post office, thinkers like Voltaire, Rousseau, and Thomas Jefferson came to see themselves as citizens of a Republic of Letters, a freethinking meritocracy that transcended national borders. It was a time of great intellectual fervor and ferment, but the Republic of Letters was "democratic only in principle," Darnton pointed out in an essay in the *New York Review of Books*: "In practice, it was dominated by the wellborn and the rich."

With the Internet, we could at last rectify that inequity. By putting digital copies of works online, Darnton has argued, we could open the collections of the country's great libraries to anyone with access to the network. We could create a "Digital Republic of Letters" that would be truly free and open and democratic. The DPLA would allow us to "realize the Enlightenment ideals on which our country was founded."

## "To Be Determined"

Harvard's Berkman Center for Internet and Society eagerly accepted Darnton's challenge. It announced late in 2010 that it would coördinate an effort to build the DPLA and turn the Enlightenment dream into an Information Age reality. The project garnered seed money from the Alfred P. Sloan Foundation and attracted a steering committee that included a host of luminaries, including both Darnton and Courant as well as the chief librarian of Stanford University, Michael Keller, and the founder of the Internet Archive, Brewster Kahle. Named to chair the committee was John Palfrey, a young Harvard law professor and coauthor of influential books about the Internet. (Palfrey plans to leave Harvard on July 1 to become headmaster of Phillips Academy Andover, the Massachusetts prep school, but he says he will remain at the helm of the DPLA.)

The Berkman Center set an ambitious goal of having the digital library begin operating, at least in some rudimentary form, by April of 2013. Over the past year and a half, the project has moved quickly on several fronts. It has held public meetings to promote the library, solicit ideas, and recruit volunteers. It has organized six working groups to wrestle with various challenges, from defining its audience to resolving technical issues. And it has conducted an open "beta sprint" competition to gather innovative operating concepts and useful software from a wide range of organizations and individuals.

When Judge Chin scuttled the Google deal last year, Darnton got a historic opportunity to cast the DPLA as the world's best chance for a universal digital library. And indeed, it has gained broad support. Its plans have been praised by, among others, the Archivist of the United States, David Ferriero, and it has forged

important partnerships, including one with Europeana, a European Commission–sponsored digital library with a similar concept.

However, the DPLA's decision to call itself a "public library" has raised hackles. At a meeting in May of last year, a group called the Chief Officers of State Library Agencies passed a resolution asking the DPLA steering committee to change the name of the project. While the state librarians expressed support for an effort to "make the cultural and scientific heritage of our country and the world freely available to all," they worried that by presenting itself as the country's public library, the DPLA could lend credence to "the unfounded belief that public libraries can be replaced in over 16,000 communities in the U.S. by a national digital library." Such a perception would make it even harder for local libraries to protect their budgets from cuts. Other critics have seen arrogance in the DPLA's assumption that a single online library can support the very different needs of scholarly researchers and the public. To strengthen its ties to public libraries, the DPLA added five public librarians to its steering committee last year, including Boston Public Library president Amy Ryan and San Francisco city librarian Luis Herrera.

The controversy over nomenclature points to a deeper problem confronting the nascent online library: its inability to define itself. The DPLA remains a mystery in many ways. No one knows precisely how it will operate or even what it will be. Some of the vagueness is deliberate. When the Berkman Center launched the initiative, it wanted major decisions to be made in a collaborative and inclusive manner, avoiding top-down decrees that might alienate any of its many constituencies. But according to current DPLA officials and others involved in the project, the 17 members of the steering committee also have fundamental disagreements about the library's mission and scope. Many important aspects of the effort remain, in Palfrey's words, "to be determined."

No consensus has been reached, for example, on the extent to which the DPLA will host digitized books on its own servers, as opposed to providing pointers to digital collections stored on the computers of other libraries and archives. Nor has the steering committee made a firm decision about which materials other than books will be included in the library. Photographs, motion pictures, audio recordings, images of objects, and even blog posts and online videos are all under consideration. Another open question, one with particularly far-reaching implications, is whether the DPLA will try to provide any sort of access to recently published books, including popular e-books. Darnton, for his part, believes that the digital library should steer clear of works published in the last five or 10 years, to avoid treading on the turf of publishers and public libraries. It would be a mistake, he warns, for the DPLA to "invade the current commercial market." But while he says he has yet to hear anyone make a convincing counterargument, he admits that his view may not be held by everyone. Palfrey will only say that the DPLA is studying the issue of e-book lending but has yet to decide whether its scope will extend to recent publications.

Also unsettled is the critical question of how the DPLA will present itself to the public. David Weinberger, a Berkman researcher who is overseeing the development of the library's technical platform, says that no decision has been reached on whether the DPLA will offer a "front-end interface," such as a website or a smart-phone app, or whether it will restrict itself to being a behind-the-scenes data clearinghouse that other organizations can tap into. The technology team's immediate goals are relatively modest. First the group wants to establish a flexible, open-source protocol for importing catalogue information and other data (such as records of how often books were borrowed) from participating institutions. Then it aims to organize that metadata into a unified database. And next it wants to provide an open programming interface for the database, with the hope of inspiring creative programmers to develop useful applications. Palfrey says that he expects the DPLA to operate its own public website, but he is wary of making any predictions about the functions of that site or the degree to which it may overlap with the online offerings of traditional libraries. While he hopes that the DPLA will be more than a "metadata repository," he also says he would consider the effort a success even if it ultimately provided just the "plumbing" required to connect diverse and far-flung collections of materials.

University of Michigan librarian Paul Courant, now on the DPLA steering committee, saw benefits for the public in Google's plan.

ANGELA J. CESERE

It's hardly surprising that a large and diverse steering committee would have difficulty reaching unanimity on complicated and weighty matters. And it's understandable that the DPLA's

leaders would be nervous about making concrete decisions that would almost certainly upset some people in the library profession and the publishing business. But there's growing tension between the heroic self-portrait that the DPLA presents to the public—its website proclaims that it "will make the cultural and scientific heritage of humanity available, free of charge, to all"—and the tentativeness and equivocation that cloud what is actually being built. If the uncertainties about the DPLA's identity and workings aren't cleared up, they could end up delaying or even waylaying the project.

## The Copyright Wall

Even if the views of the steering committee members were to come into harmony tomorrow, the ultimate form of the DPLA would remain hazy. The biggest question hanging over the project is one that can't be decided by executive fiat, or even by methodical consensus building. It's the same question that confronted Google Book Search and that bedevils every other effort to create an expansive online library: how do you navigate the country's onerous copyright restrictions? "The legal problems are staggering," Darnton says.

The U.S. Congress passed the first federal copyright law in 1790. Following English precedent, lawmakers sought to strike a reasonable balance between the desire of writers to earn a living and the benefit to society of giving people free access to the ideas of others. The law allowed "Authors and Proprietors" of "Maps, Charts and Books" to register a copyright in their work for 14 years and, if they were still alive at the end of that term, to renew the copyright for another 14 years. By limiting copy protections to a maximum of 28 years, the legislators guaranteed that no book would remain under private control for very long. And by requiring that copyrights be formally registered, they ensured that most works would immediately enter the public domain. Of the 13,000 books published in the country during the decade following the law's enactment, fewer than 600 were registered for copyright, according to historian John Tebbel.

*Early copyright legislation guaranteed that no book would remain under private control for very long. Most works immediately entered the public domain.*

Beginning in the 1970s, Congress developed a radically different approach. Under pressure from film studios and other media and entertainment companies, it passed a series of bills that dramatically lengthened the term of copyright, not only for new books but retroactively for books published throughout most of the last century. Today, copyright in a work extends 70 years beyond the date of the author's death. Congress also removed the requirement that an author register a copyright—and, again, it applied the change retroactively. Now a copyright is established for any work the moment it's created. Even when writers have no interest in claiming a copyright, they get one—and their works remain out of the public domain for decades. The upshot is that most books or articles written since 1923 remain off limits for unauthorized copying and distribution. Other nations have enacted similar policies, as part of an effort to establish international standards for trade in intellectual property.

Politicians make lousy futurists. As Google and the DPLA can testify, the copyright changes put severe constraints on any attempt to scan, store, and provide online access to books published during most of the last 100 years. Moreover, the removal of the registration requirement means that millions of so-called orphan books—ones whose copyright holders either are unknown or can't be found—now lie beyond the reach of online libraries. Copyright protections are vitally important to ensuring that writers and artists have the wherewithal to create their works. But it's hard to look at the current situation without concluding that the restric-

## Cliffs Notes on a Controversy

### The Vision

The people behind the DPLA want to offer free online access to the vast amount of knowledge stored in major libraries.

### Technical Issues

Will the DPLA run its own servers with digitized copies of books, or will it be an interface to libraries' own online services? The answer is not yet clear.

### Logistical Issues

The DPLA also has to decide whether to try to include recently published books, including e-books—and whether it will have material other than books as well.

### Legal Issues

Because of copyright restrictions, millions of books are off limits to online databases. Even the metadata that libraries use to organize their collections is often proprietary.

### Next Steps

The DPLA will probably be rudimentary when it opens next year. Meanwhile, Google says it still hopes to find ways to further its massive book-scanning project.

Internet Archive founder Brewster Kahle says the DPLA should support a network of libraries and not build a centralized one.

JEFF CHIU/AP

tions have become so broad as to hamper the very creativity they were supposed to encourage. "Innovation is often being restricted today for legal reasons, not technological ones," says David K. Levine, an economist at Washington University in St. Louis and coauthor of *Against Intellectual Monopoly*. In many areas, he says, "people aren't creating new products because they fear a nightmare of copyright litigation."

There's a further twist. Books and other creative works behind the copyright wall aren't all that could be off limits. Much of the metadata that libraries employ to catalogue their holdings falls into a gray area with regard to how it can be reused. That's because many libraries purchase or license metadata from commercial suppliers or from the OCLC, a large library coöperative that syndicates an array of cataloguing information. And because librarians have long used metadata from many sources in classifying their holdings, it can be extraordinarily difficult to sort out what's under license and what's not, or who owns what rights. The confusion makes even the DPLA's seemingly modest effort to collect metadata fraught with complications, according to David Weinberger. He says the DPLA is making progress at solving this problem, but when the library opens its virtual doors, patrons may have to make do with scanty descriptions of its contents.

## Dreams and Realities

Some scholars believe that copyright restrictions will frustrate any attempt to create a universal online library unless Congress changes the law. James Grimmelmann, a copyright expert at New York Law School, feels that it will be "very, very hard" to include orphan works in a digital database without new legislation. Siva Vaidyhanathan, a University of Virginia media studies professor who wants to build an international project to organize research materials online, believes that major changes in copyright law are essential to creating a digital library that includes recent works. He senses that it may take many years of public pressure to get politicians to deliver the necessary remedies.

While Palfrey is hesitant to discuss legal issues, he expresses some hope that progress can be made without congressional action. He feels that the DPLA may be able to hash out an agreement with publishers and authors that would enable it to offer access to at least some of the orphans and other books published since 1923. The DPLA may, according to some copyright experts, have an advantage over Google Book Search in negotiating such an agreement and getting it blessed by the courts: it's a nonprofit.

The DPLA has made it clear that it will be meticulous in respecting copyrights. If it can't find a way around current legal constraints, whether through negotiation or through legislation, it will have to limit its scope to books that are already in the public domain. And in that case, it's hard to see how it would be able to distinguish itself. After all, the Web already offers plenty of sources for public-domain books. Google still provides full-text, searchable copies of millions of volumes published before 1923. So do the HathiTrust, a vast book database run by a consortium of libraries, and Brewster Kahle's Internet Archive. Amazon's Kindle Store offers thousands of classic books free. And there's the venerable Project Gutenberg, which has been transcribing public-domain texts and putting them online since 1971 (when the project's creator typed the Declaration of Independence into a mainframe at the University of Illinois). Although the DPLA may be able to offer some valuable features of its own, including the ability to search collections of rare documents held by research libraries, those features would probably interest only a small group of scholars.

Despite the challenges it faces, the Digital Public Library of America has an enthusiastic corps of volunteers and some generous contributors. It seems likely that by this time next year, it will have reached its first milestone and begun operating a metadata exchange of some sort. But what happens after that? Will the library be able to extend the scope of its collection beyond the early years of the last century? Will it be able to offer services that spark the interest of the public? If the DPLA is nothing more than plumbing, the project will have failed to live up to its grand name and its even grander promise. The dream of H. G. Wells—and, for that matter, Robert Darnton—will have been deferred once again. tr

NICHOLAS CARR WRITES ABOUT TECHNOLOGY AND CULTURE FOR SEVERAL PUBLICATIONS, INCLUDING THE *ATLANTIC*. HIS MOST RECENT BOOK IS *THE SHALLOWS: WHAT THE INTERNET IS DOING TO OUR BRAINS*.

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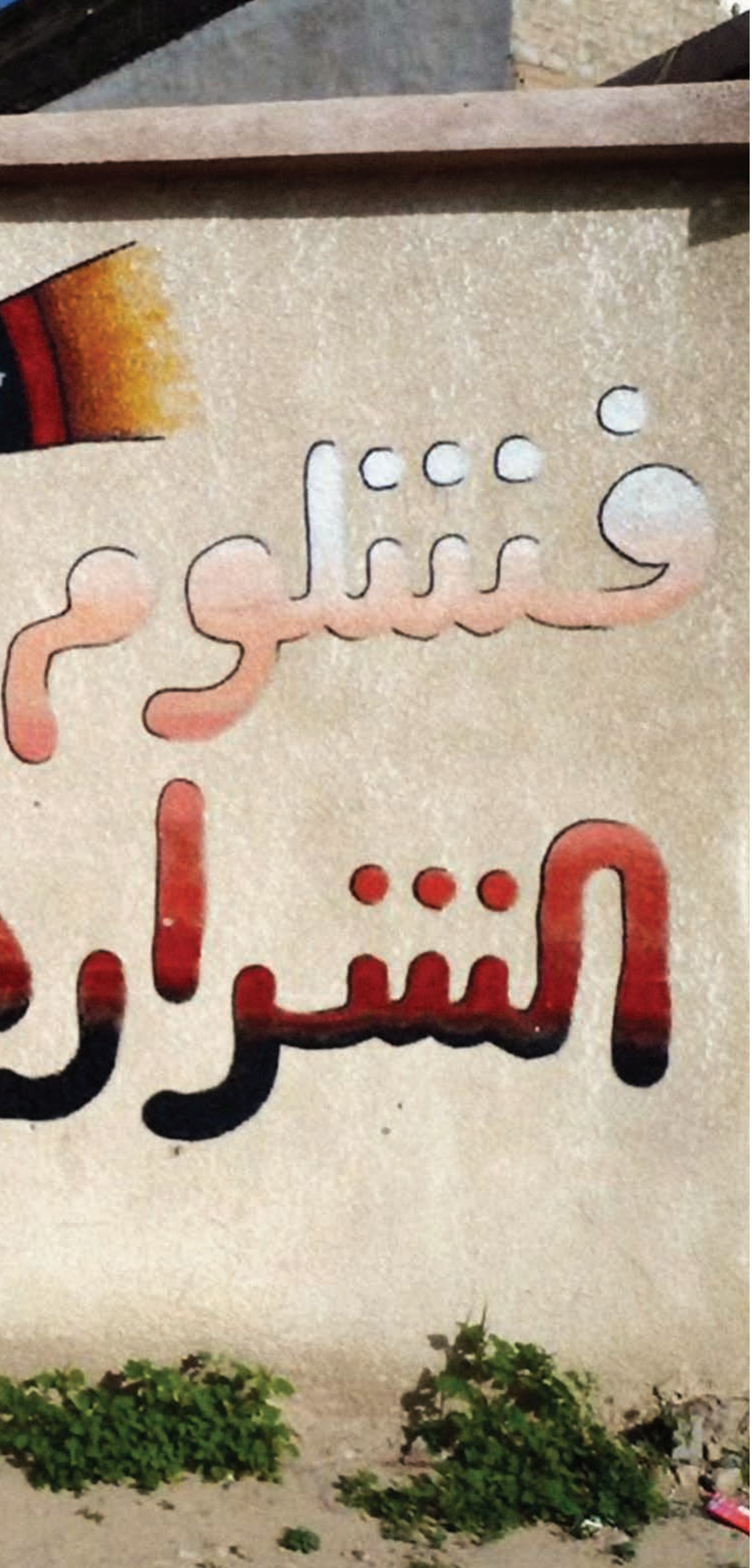


# People Power 2.0

## How civilians helped win the Libyan information war

By
JOHN POLLOCK

After weeks of skirmishes in the Nafusa Mountains southwest of Tripoli, Sifaw Twawa and his brigade of freedom fighters are at a standstill. It's a mid-April night in 2011, and Twawa's men are frightened. Lightly armed and hidden only by trees, they are a stone's throw from one of four Grad 122-millimeter multiple-rocket launchers laying down a barrage on Yefren, their besieged hometown. These weapons can fire up to 40 unguided rockets in 20 seconds. Each round carries a high-explosive fragmentation warhead weighing 40 pounds. They urgently need to know how to deal with this, or they will have to pull back. Twawa's cell phone rings.

**THE FORCE OF LAUGHTER**
Graffiti on a wall in Tripoli represents the Libyan leader, Colonel Qaddafi, as a fleeing rat.

**THE ACTIVIST:** Stephanie Lamy (above) abandoned her business to help the Libyan revolution. **THE MARTYR:** Mohammed Nabbous (opposite) was killed by a sniper while capturing video in Benghazi.

ABOVE: EMMANUEL FRADIN; OPPOSITE AND PREVIOUS: JOHN POLLOCK

Two friends are on the line, via a Skype conference call. Nureddin Ashammakhi is in Finland, where he heads a research team developing biomaterials technology, and Khalid Hatashe, a medical doctor, is in the United Kingdom. The Qaddafi regime trained Hatashe on Grads during his compulsory military service. He explains that Twawa's *katiba*—brigade—is well short of the Grad's minimum range: at this distance, any rockets fired would shoot past them. Hatashe adds that the launcher can be triggered from several hundred feet away using an electric cable, so the enemy may not be in or near the launch vehicle. Twawa's men successfully attack the Grad—all because two civilians briefed their leader, over Skype, in a battlefield a continent away.

Indeed, civilians have "rushed the field," says David Kilcullen, author of *The Accidental Guerrilla*, a renowned expert on counterinsurgency and a former special advisor to General David Petraeus during the Iraq War. Their communications can now directly affect a military operation's dynamics. "Information networks," he says, "will define the future of conflicts." That future started unfurling when Libyan networks—and a long list of global activists—began an information war against Qaddafi. Thousands of civilians took part, but one of the most important was a man who, to paraphrase Woodrow Wilson, used not only all the brains he had but all the brains he could borrow.

## Mo Better

THE WAR AGAINST QADDAFI WAS FOUGHT with global brains, NATO brawn, and Libyan blood. But it took brains and blood to get the brawn. On February 18, three days into the protests that would swell into the successful revolt against the regime, Libya went offline. Internet and cell-phone access was cut or unreliable for the duration, and people used whatever limited connections they could. In Benghazi, Mohammed "Mo" Nabbous realized he had the knowledge and the equipment, from an ISP business he had owned, to lash together a satellite Internet uplink. With supporters shielding his body from potential snipers, Nabbous set up dishes, and nine live webcams, for his online TV channel Libya Alhurra ("Libya the Free"), running 24/7 on Livestream.

Nabbous had pitched a brightly lit virtual tent in a darkening Libya. As Benghazi descended into fighting that killed hundreds and left thousands injured, he gave interviews to international media outlets such as CNN and the BBC. He also connected with supporters and activists from dozens of countries, among whom a cadre of information warriors soon emerged.

Stephanie Lamy was one. A self-described strategic communications consultant and single mother living in Paris, she was using the Egyptian and Libyan revolutions to explain her work to her nine-year-old daughter. They searched Google and found Libya Alhurra TV; Lamy was hooked. "When I saw the cries for help on Livestream, I knew my skills were just perfect for this situation, and it was my duty to help," she says. She abandoned her business and started working up to 24 hours a day. It was a situation where "each action counted."

In its first six weeks, the channel served 25 million "viewer minutes" to more than 452,000 unique viewers. Nabbous had only enough bandwidth to broadcast, so volunteers stepped forward to capture and upload video. Livestream took an active

role, too: it archived backups several times a day, dedicated a security team to guard against hackers, and waived its fees. Others ran Facebook groups or monitored Twitter, pasting tweets and links into the chat box. They shared first-aid information in Arabic and transcribed or roughly translated interviews in close to real time. "All of us were on a fast learning curve," says Lamy. "Tanks were moving in, people were getting shelled, people were getting massacred."

On March 19, Qaddafi launched an assault on Benghazi. With shells exploding, Nabbous said, "No one is going to believe what they are going to see right now!" before heading out to report live. He was still broadcasting when a sniper shot him. Hours after Nabbous's death, French fighter jets strafed the heavy armor attacking Benghazi. His widow, Samra Naas, pregnant with their first child, broadcast in his place: "What he started has got to go on, no matter what happens." Along with friends and family, three women she had never met spent much of the night comforting her, as best they could, over Skype.

## The Hit List

AMONG THEM WAS CHARLIE FARAH, A Lebanese-American radio producer. She arranged technical support for Libya Alhurra TV, as well as two-way satellite subscriptions for freedom fighters. That required their trust. "When someone you've never met says they'll pay for your satellite, they get your GPS coördinates," she points out. "In the wrong hands, a missile could follow."


**THE FREEDOM FIGHTER:** Sifaw Twawa was advised by civilians outside Libya about how to defeat Qaddafi's weapons.

Most freedom fighters were civilians with no first-aid or weapons training. Farah started teaching what she could about basic triage, planning escape routes, and how to fire and move. She showed people how to share files using YouSendIt, because guards at regime checkpoints were now searching for information being smuggled on portable media. (Rebels in Sabratha had hidden thumb drives in their hair; weapons were slung under their sheep.) For the fighters, discovery could mean imprisonment, torture, or execution.

Although those in Libya were most at risk, Qaddafi had a grim reputation for lashing out overseas. In addition to his involvement in the Berlin nightclub bombing of 1986 and the explosion of Pan Am Flight 103 over Lockerbie, Scotland, in 1988, he supported a bizarre collection of terrorist groups and hunted individual dissidents. In the 1980s, he had dozens assassinated around the world.

Mustafa Abushagur, who opposed the regime for decades, managed to escape that fate. A microsystems engineer and entrepreneur, he was the founding president of Dubai RIT (Rochester Institute of Technology). In 1980, he was doing graduate study at Caltech when the FBI visited and warned him: "Listen, you're on a hit list." He started wearing cotton gloves to avoid leaving fingerprints when packing and mailing anti-Qaddafi magazines. When the revolution began, he used Facebook to keep abreast of fast-changing events and ultimately returned to Libya, where he is now interim deputy prime minister. "The information war," he says, "is what made the revolution succeed."

## The Cousinate

SOME INFORMATION WARRIORS SET UP their own operations. For Rida Benfayed, an orthopedic surgeon then based in Denver, getting online was the first priority when he reached his hometown of Tobruk, 290 miles east of Benghazi. Benfayed got hold of the city's only two-way satellite Internet connection and started accepting hundreds of requests to connect on Skype. He organized his contacts into six categories: English media, Arabic media, medical, ground information, politicians, and intelligence. His contacts included ambassadors and doctors, journalists and freedom fighters. A source of high-grade military intelligence soon turned his ad hoc operation into a control room.

Someone who claimed to be a retired European intelligence officer contacted Stephanie Lamy. The detailed intelligence he sent appeared authentic: it included the number, location, and movements of Qaddafi's troops and heavy weapons. There were even updates as the regime's long armored column approached Benghazi. Lamy passed the intelligence on to Benfayed, who shared it with Mustafa Abdul Jalil, the Libyan justice minister who had defected to become chair of the National Transitional Council (NTC) and the opposition's de facto leader. (Today, he is the official leader of Libya's interim government.)

For a few weeks during the period before NATO recognized the NTC, and before the source disappeared as suddenly as he had surfaced, he was a mother lode of military intelligence. He revealed that the regime's

standard operating procedure was to cut an area's cell-phone coverage three days before an attack; suggested strategic plans to protect Benghazi if the U.N. Security Council didn't act; and explained how and where to attack the regime's tanks. With Jalil's blessing, Benfayed set up ground information links with the front lines and expanded his team to around 30 people, including opposition army, navy, and air force officers; internal and foreign media liaisons; and medical and IT specialists. The room was soon taking in so much live local information that one delighted visitor said, "It's just like Al Jazeera!"

When the opposition smuggled weapons and humanitarian aid into Misrata's port, which was being heavily shelled by the regime, Benfayed gave NATO the time of the run, and the size and name of each boat, to reduce the chance of friendly fire. Benfayed ran his control room until he was confident he had directly linked NATO to the key leaders in each of his networks.

Libya's six million or so people are concentrated in a coastal belt of cities and connected in a kind of "cousinate" of extensive personal and family networks. The trust embedded in these networks was valuable to the opposition: a cousin's cousin could check *bona fides*, or a friend's cousin could supply intelligence from within the regime's security apparatus. Meanwhile, Qaddafi's brittle hierarchy, absorbed in the kind of capricious and despotic interventions dubbed "sultanism," was isolated from this social structure and plagued by distrust.

Libyans lived in fear of their sultan for over four decades, but their tight social networks proved highly resilient when the delusion that people believed in the regime—what Kilcullen calls "the presumed consensus"—fell away. At that point, the cousinate took on the sultanists.

## Misrata Calling

GIHAN BADI, A U.K.-BASED ARCHITECT, remembers overcoming that fear. Before the uprising, she was scared: though she knew that protests were planned for February 17, she deleted any talk of them from her Facebook group for Libyans. On February 15, in a call to family in Benghazi, she learned that the protests had, unexpectedly, already started. Using a kind of pseudonym, Juhaina Mustafa, she rang Al Jazeera Mubasher, the network's live phone-in channel, to share the news. Thanks to a connection established through her brother, she arranged interviews for Nabbous with Al Jazeera and the BBC. She began giving journalists the numbers of dozens of people in Libya, making sure to verify the trustworthiness of contacts she did not personally know. Truthful and reliable information mattered, she says, not least because "we are not faking things anymore."

Qaddafi's brittle hierarchy, absorbed in the kind of capricious and despotic interventions dubbed "sultanism," was isolated and plagued by distrust.

"Juhaina Mustafa" was denounced on Libyan state TV. Worried about the security of her own phone, she bought batches of prepaid phone cards. She discovered a useful rule of thumb: Qaddafi stooges making repeated Skype requests to connect with her had short fuses. "For the first three messages they are nice," she says. "Then on the fourth they become angry and start saying, 'We will kill you! We know who you are!'" Other contacts were patient, realizing how busy she must be. A working mother, she was now even busier and focused on a new emergency: Misrata.

Libya's third-largest city, strategically located between Tripoli and Benghazi, was besieged. For months, heavy artillery and tanks pounded Misrata from outside. Inside, dozens of snipers—including female mercenaries from Colombia—dominated the city center. "There were dead bodies in the streets, unrecoverable because of the snipers," says Marwan Tanton, a citizen journalist with Freedom Group Misrata, a group of students turned reporters, carrying cameras and guns. "Dogs were eating them."

Stephanie Lamy, Rida Benfayed, and Badi's husband, Nagi Idris, were among many scrambling to get humanitarian supplies to Misrata and to alert the world to an

**THE NETWORKER:** Gihan Badi (above), a U.K.-based architect, connected the BBC, Al Jazeera, and others to the Libyan opposition. **CROWDSOURCING:** Badi's Twitter stream (opposite) broadcast operations.

JO HANLEY

unfolding disaster. They worked to smuggle in by sea the first international journalists, including Fred Pleitgen of CNN. (They played a similar role for the hitherto underreported fighting in the Nafusa Mountains.)

Identifying weapons was another urgent task in Misrata, as elsewhere. Andy Carvin of NPR (a member of the 2005 TR35) used Twitter to crowdsource weapons knowledge. It took his followers just under 40 minutes to identify unusual Chinese parachute land mines found in Misrata's port area—their first known use in the war (an extraordinary event preserved on Storify).

As with Wikipedia, such expertise might come from anyone—like Steen Kirby, a high-school student in the state of Georgia. As well as identifying weaponry, Kirby pulled together a group through Twitter to quickly produce English and Arabic guides to using an AK47, building makeshift Grad artillery shelters, and handling mines and unexploded ordnance, as well as detailed medical handbooks for use in the field. These were shared with freedom fighters in Tripoli, Misrata, and the Nafusa Mountains.

The Misratans showed impressive ingenuity. Engineers hacked new weapons—including a remote-controlled machine gun mounted on a children's toy—and adapted technology on the fly. Laptops, Google Earth on CD-ROMs, and iPhone compasses gave the freedom fighters range. After a rocket was fired, a spotter confirmed the hit, reporting that it had landed, for example, "30 yards from the restaurant." They then calculated the precise distance on Google Earth and used the compass, along with angle and distance tables, to make adjustments.

Freedom Group Misrata had compelling video but limited signal strength. The citizen journalists fixed this by bridging pairs of mobile Internet dongles to share their increasingly professional content (marked with their logo).

After 40 years of silence, Libya is talking again. The most noticeable thing about the country's urban landscape today is the graffiti on almost every wall. War stories are frequently shared by photo and video over ubiquitous camera phones and computers. While many are too horrific for mainstream media, they circulate widely on YouTube and Facebook. A clip on a mercenary's captured cell phone revealed the killing of 37 people in the Nafusa Mountains. But other videos, taken on mobile devices inside the country, were widely broadcast on Western television. Knowledge within the U.N. Security Council of atrocities in Libya had a powerful influence on its members' vote on the no-fly zone. That vote brought the brawn into the equation.

## The Brawn

UNSC RESOLUTION 1973 RESULTED IN nearly immediate operations by several nations, led by the United States, before they handed control to NATO's Operation Unified Protector (OUP). A naval blockade used surface ships and submarines from 12 countries, while air power came from NATO and 15 countries—including Qatar, the United Arab Emirates, and Jordan. In 222 days, some 26,000 sorties were flown, with more than 9,600 strike missions hitting about 6,000 targets.

For weeks, the Libya Alhurra network tracked strikes via a live air traffic control feed from Malta. David Cenciotti, a military aviation blogger, notes that traffic entering Libyan airspace would identify itself, for

example, as a Predator drone "going tactical"—switching radio frequencies to contact the tactical control unit. Strike confirmations, recalls Stephanie Lamy, emerged on Twitter "in about six to eight minutes, on average." NATO says it took "one or two minutes" for the initial confirmation of a strike, although it had a singular advantage: the "Air Tasking Order" showing where and when each aircraft was due to strike.

This was a rare example of unofficial NATO information reaching civilian networks. The reverse was more common: civilians sent information to NATO, which had discreetly sought out key information, including multiple independent sources and precise coördinates. This communication was very much one-way; there was little attempt at relationship building with the new breed of technologically adept and highly networked activists.

Publicly, NATO and its secretary general, Anders Fogh Rasmussen, do use social media, including Twitter, Facebook, and a video blog—albeit as an adjunct to standard press-office fare. They took the trouble to ensure that the first announcement of the end of the Libyan operation came via Twitter and Facebook. Further, in one press briefing, NATO explained that its "fusion center" used open-source information like Twitter to deliver "usable intelligence." Less publicly, the story is somewhat different.

## The Insider

THE EXPERIENCE OF AN ACTIVE FRENCH navy officer, who spoke to *Technology Review* on condition of anonymity, suggests a high degree of wariness in the military about social media and Web communities. The officer, whom I will call Eric Martin, is an expert in combat systems and tactical data links—used by NATO and the United States in command, control, and communications. Before being assigned to join the naval operation, he had become intrigued by the high level of "open-source intelligence" to be found on social media.

After about a hundred hours of work, Martin had 250 or so direct contacts in Libya and elsewhere. He created, in effect, a private intelligence network. Initially, he expected only "ambient" or background information, but the intelligence he gathered soon proved useful for both strategy and tactics. He tried alerting his hierarchy to its potential for following the flow of action on the ground. It took a while for them to accept this. "They were very afraid in the beginning, because they had no control," he says, "[so] I ran a kind of laboratory." He set up a desk and was given no military intelligence. His captain asked specific questions and matched Martin's performance against more formal intelligence channels. Precise comparison is difficult, but Martin estimates that eventually 80 percent of the intelligence used by his vessel came from his sources.

**An active French navy officer was convinced that his unofficial network left him better informed than counterparts relying on official French intelligence.**

Martin believes that the U.S. and U.K. use software to analyze social media, which he assumes provided input during the Libyan conflict. Indeed, the CIA already tracks social media, and the Defense Advanced Research Projects Agency (DARPA), which funded the development of the Internet, is currently exploring these channels. If countries can learn to exchange such information at the right level, at the right time, it might be possible to avoid tragic errors, Martin believes. But he asks: "Is NATO able to make the right evolution, with the right software, with the right time line? I don't think so."

Martin sees several problems. NATO is a complex coalition riddled with cultural and linguistic barriers, social media are not appreciated or well understood by its leaders, and verifying the identities of informal sources takes considerable time. Even so, he is convinced that his unofficial network left him better informed than counterparts relying on official French intelligence channels.

## The Rear Admiral

CHARLIE FARAH IS ONE OF MANY WHO wish NATO had established a rapport with active nonmilitary networks, or at least key


**THE OLD GUARD:** Rear Admiral Russell Harding (above) said it was "not for us to improve communications" with the Libyan opposition. **AFTERMATH:** NATO bombing raids damaged parts of Tripoli (opposite).

ABOVE: AP; OPPOSITE: JOHN POLLOCK

nodes within them. By making targeting more efficient, she believes, this could have reduced casualties, saved money, and possibly shortened the war.

One incident in which better links might have helped came on April 7, when—a week after assuming control of operations—NATO bombed a convoy of tanks and other armor captured by freedom fighters. There were several deaths.

Farah, Lamy, and many others had known for days that the tanks were in freedom fighters' hands. Whether the incident was due simply to rebels' being mistaken for pro-Qaddafi forces is somewhat murky. Some sources say that NATO may have been the victim of disinformation supplied by General Abdul Fattah Younes, a senior military defector later assassinated by opposition forces. Others say the freedom fighters had been warned by NATO not to cross a "red line."

The next day, Rear Admiral Russell Harding, British deputy commander of NATO's Operation Unified Protector, responded to a reporter's questions at a press briefing. "I'm not apologizing," he said. "We had no information that the opposition forces were using tanks." Asked how NATO was trying to improve communications with the freedom fighters to prevent more such incidents, he was blunt: "It's not for us to improve communications."

One NATO official to whom *Technology Review* spoke did confirm that NATO took advantage of civilian communications coming out of Libya, adding that the organization had never before had this kind of information. However, the role of civilians in providing intelligence, up to and including identifying targets, is an uncomfortable subject for NATO. Alongside a military concern for operations security, there are political sensitivities, given that countries including South Africa, Russia, and China complained that NATO forces were exceeding the mandate to protect civilians. Yet throughout the conflict, civilians did feed intelligence to NATO: in fact, they were asked to.

## Social Network Intelligence

WHEN NATO CALLED NAGI IDRIS OUT OF the blue in search of intelligence, he was "very, very scared." He was a research scientist living in Leeds, England, with his wife, Gihan Badi, and young son; the intelligence world was new to him. His contribution to the Libyan effort had been to gather information about the medical needs of civilians and freedom fighters in Benghazi, Misrata, and the Nafusa Mountains, raise the funds to address those needs, and secure humanitarian supplies and transport. As Libyans, Idris and Badi decided to call the British government to ask whether the NATO caller was a real contact and, if so, whether they should coöperate. It took half an hour for an official to confirm the name and verify that U.K. authorities were happy for them to work with NATO.

Their contact was from NATO's Civil-Military Co-operation (CIMIC) group, whose website says its task is to "intensify the involvement of civilian actors in a more comprehensive and integrated way into planning." With her husband concentrating on humanitarian relief, Badi took the lead, supplying regular updates including, at NATO's request, precise coördinates. Badi knew NATO wanted multiple sources for cross-checking, so she created Chinese walls to separate herself from oth-


ers—including her husband—who had their own networks.

Another Libyan civilian who contributed important intelligence is a man I will call Asim (he requested anonymity because he believes that his work, providing targeting information to NATO, led directly to the deaths of people who may still have family in Libya). An influential, well-connected Libyan working in the media, Asim smuggled most of his family out of the country and then set up "op rooms" in Tunisia, Dubai, and Spain. "I don't think any intelligence agency in the world knows Qaddafi as well as the Libyan people," he says.

Asim's network of information smugglers brought thumb drives and disks out of Tripoli and got approximately a hundred Thuraya satellite phones into the country. They supplied NATO with blueprints, troop locations and movements, and a detailed diagram of Qaddafi's family connections. His estimate of Qaddafi troop numbers in Brega, between Benghazi and Misrata, came through a contact in the catering company supplying their meals.

Asim's op rooms conveyed their intelligence to NATO, he says, via "a super-node in Dubai." He found himself working with people in all sorts of professions, from video editors to cartographers: he remembers one "girl" he found through Twitter who "would punch in the locations of snipers on Google Maps." The map was shared online and on the ground.

**FREE LIBYA:** Artwork in a museum (above) in the Amazigh village of Yefren commemorates the war. **GRATITUDE:** Graffiti in Misrata (opposite) thanks NATO for its part in overthrowing the regime.

JOHN POLLOCK

Like any civil war, this conflict was dynamic, complex, and unpleasant. Watching the combat footage—a blur of street-fighting men, nondescript architecture, gunfire, explosions, and crowds that could be either angry or exultant—it is hard to tell exactly what is happening or where. But, simplifying, what happened is this: once Benghazi was secured at the cost of many uprisings, battles, and skirmishes throughout the country, two spearheads emerged: in Misrata and in the Nafusa

Mountains. They were a pincer whose object was Tripoli.

## Information Power

IN TRIPOLI, QADDAFI CREATED A GILDED cage in the opulent Rixos Hotel for the closely chaperoned international media. They had access to the official voice of government, but they distrusted what they were told. Yet from the start, Qaddafi's communications had been undermined by unofficial sources: by Mo Nabbous and the Libya Alhurra TV network, by students like Freedom Group Misrata, and by the growing number of international journalists in opposition-held areas. On the ground, individuals were also blurring the line between journalism and fighting. Twenty-one-year-old Inas Mohamed, a student of English literature from Yefren, not only smuggled gelignite, an explosive, past Tripoli checkpoints but wrote, printed, shared, and scattered on the street hundreds of samizdat flyers.

Thanks to technology, collaborators could be anywhere. In Finland, as well as helping advise on attacking Grads, Nureddin Ashammakhi set up LibyaHurra.info as a direct response to Qaddafi's disinformation campaign. A global brigade of volunteers published daily reports from Libya in 10 languages, including Chinese, Russian, and Tamazight (the language of the Berbers, who prefer to be called Amazigh—"free people"). As hundreds of thousands of noncombatants fled Libya, Ashammakhi returned from Finland and joined the much smaller but significant flow

According to a U.S. Army field manual, "information has become as important as lethal action in determining the outcome of operations."

of exiles and expats heading in the opposition direction. He set up field hospitals near Yefren to treat the wounded of both sides, and was thus active in both the military and information wars.

Ashammakhi instinctively reaches for technological analogies to capture the complexity of this conflict. He likens those on the ground in the information war to a coöperative network of sensors giving feedback "continuously, dynamically, and in real time." He compares the way self-organizing civilians come together in support of military operations to CPU scavenging, where spare capacity on individual computers is pooled across a grid. He cites moving examples of people stepping forward to fill a gap: strangers who left breakfast for hungry doctors; Yefren's council leader, unasked, starting to clean the hospital—a task he quietly continued even on the day after his son was killed. Ashammakhi contrasts this with Qaddafi's rigid hierarchy, obsessively focused on the leader and ultimately overthrown by a "network of nodes."


The world's nodes and networks are multiplying and growing denser: a third of the world's population is online, and 45 percent of those people are under 25. Cellphone penetration in the developing world reached 79 percent in 2011. Cisco estimates that by 2015, more people in sub-Saharan Africa, South and Southeast Asia, and the Middle East will have mobile Internet access than have electricity at home. Across much of the world, this new information power sits uncomfortably upon archaic layers of corrupt or inefficient governance.

In today's world, as the U.S. Army Field Manual for Operations notes, "information has become as important as lethal action in determining the outcome of operations." Now the traditional networks through which information flows—from the mass media to military units—are being rewired. By and large, military and intelligence organizations still see the new networks, and the coöperation and collaboration they engender, as a threat, not an opportunity.

But as military budgets shrink, the world urbanizes, and Kilcullen's "presumed consensus" collapses, cheap handheld technology is making citizen networks an inevitable feature of the information battle space. tr

JOHN POLLOCK IS A CONTRIBUTING EDITOR TO *TECHNOLOGY REVIEW*. HE WROTE ABOUT THE USES OF SOCIAL MEDIA DURING THE ARAB SPRING IN THE SEPTEMBER/OCTOBER 2011 ISSUE.

technology review

BUSINESS IMPACT

# Computers Storm the Grid



Energy prices and carbon dioxide emissions are rising. But the cost of computing is falling. In this issue and online, *TR* analyzes the idea that IT could be the cheapest solution to the energy problem.

GETTY IMAGES/DIGITAL VISION; ISTOCKPHOTO

THE BIG QUESTION

# Inventing the Cleanweb

The energy problem is humanity's greatest challenge.
Here's one way information technology can provide some solutions.

By SUNIL PAUL AND NICK ALLEN

At the height of the technology bubble in March of 2000, spending on Internet infrastructure had exploded, Cisco Systems had a market value of over $550 billion, and venture capitalists were pumping millions into anything that ended in ".com." Over the next three years, 655 telecom companies would go bankrupt, and more than a trillion dollars would vanish from stock exchanges.

A disaster, right? It felt like one at the time. Raising money for an Internet startup became nearly impossible on Silicon Valley's Sand Hill Road. Yet all that investment in the infrastructure of the Internet—the switches, the routers, and the fiber-optic cable—drastically reduced the costs of bandwidth and made possible the application layer, the things we love about the Internet. Today we use information technology to do things we didn't imagine circa 2000, like buying shoes without trying them on first. All this was accomplished with software and clever ideas for using the available infrastructure.

We see in this story important analogies with clean energy. Advanced biofuels, electric cars, and solar power are living through their own boom and bust times. The cost of solar panels has fallen from over $4 per watt to less than $1 in just four years. That's bad for solar investors, and panel makers are struggling to survive. Some have gone out of business. But at the same time, infrastructure is being built. Spending on solar, wind, and other forms of renewable energy has exploded, reaching $250 billion per year.

Raising venture capital for capital-intensive clean tech, especially for early-stage companies involved in new types of energy production, has become increasingly difficult. That has investors like us thinking about new ways to apply our dollars to the energy problem. We believe the next opportunity is what we call the "cleanweb"—a form of clean tech that takes advantage of the Internet, social media, and mobile communications to alter how we consume resources, relate to the world, interact with each other, and pursue economic growth.

We think that IT and fast-growing Web business models can expand the use of renewable energy. These days the challenges that industries like solar, wind, and biofuels face are often not about fundamental science. Many of the big breakthroughs have already taken place, and in some circumstances, electricity from wind and solar is already cheaper than electricity from fossil fuels. What hampers these industries now is poor sales channels, complex financing and incentives, and a failure to communicate with consumers.

That makes them ripe for disruption by the application of IT, which will drive the next phase of cost reduction and implementation, especially for solar. The price of a rooftop solar installation has dropped by half in the last few years, and most of the remaining price comes from soft costs like site evaluation, customer acquisition, and financing. U.S. solar companies commonly spend around $2,500 to acquire each new customer. Imagine the frustration when a customer doesn't qualify for financing or an installer arrives at a home only to discover that a tree shading the roof makes the project uneconomical. That's a waste.

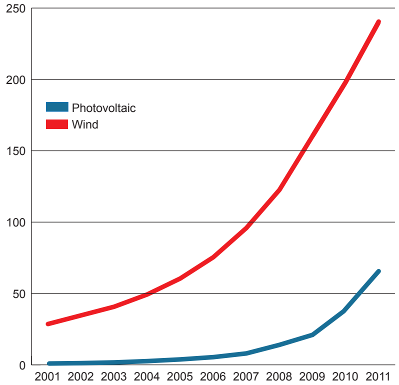
Better information can reduce these inefficiencies. OneRoof Energy, a solar company we've invested in, uses satellite imagery to remotely work up a customer's project, determining its cost and viability long before a truck ever rolls out to the house. Another company we're backing, Solar Mosaic, is raising money for solar installations via online crowdsourced loans. We estimate that IT-driven solutions alone can reduce solar costs by another 75 percent; if so, solar could become decisively cheaper than electricity from coal. Eventually it could meet 15 to 20 percent of U.S. electricity needs.

Unlike traditional clean tech, the cleanweb doesn't always have to do with produc-

## BOOM TIMES

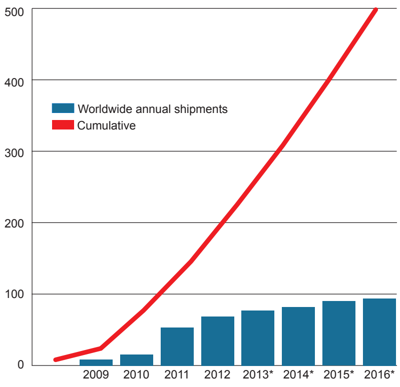
The growth of renewable power and smart-grid technologies

**Worldwide photovoltaic and wind power capacity (in gigawatts)**




Source: GTM Research, Bloomberg New Energy Finance

**Worldwide smart-meter shipments (millions of units)**




Source: NPD * projection

ing energy. Consider peer-to-peer online markets that foster collaborative consumption. Airbnb is an online service that allows consumers to rent local accommodations in people's homes instead of hotels. The company probably wasn't founded with energy efficiency in mind, but given that hotels are three times as energy intensive as the average home, the cumulative impact of reducing hotel use could be significant. The company rents more than 10,000 rooms nightly; while that's less than a tenth the number of hotel rooms in Las Vegas alone, keep in mind that these savings are organized almost entirely through a computer program, and Airbnb is growing extremely fast. That's the idea: obtain clean-tech benefits at the speed and scale the Web can create.

Computers programs are only as good as the data we feed them. That is a major limitation, but it's one we see being rapidly overcome. There are currently 2.5 billion computing devices connected to the Internet, including smart phones, GPS locators on shipping pallets, and even volume sensors on trash cans. The number of networked devices is expected to grow to 100 billion in the next 10 years. With the emergence of this "Internet of things" will come a vast increase in data that can be sliced and diced, creating new opportunities to unearth patterns and possibilities for energy savings.

Utilities across the United States had installed 26 million smart meters on homes by the end of last year, and something similar is occurring in China and Europe. These meters, combined with sensors in dishwashers or thermostats, will produce much more detailed information about a home's patterns of energy use, and this information will help consumers shift energy use to times when it's least expensive. The White House's Green Button initiative, which gets utilities to provide customers with their energy-use data, will go a long way in enabling the army of developers out there to create the next great home-energy app.

According to the Cleantech Group, venture capitalists have invested in 414 cleanweb financing rounds since 2009, representing 18 percent of all clean-tech deals. Entrepreneurs, designers, and engineers are coming together in weekend-long hackathon events around the country to see what kinds of apps they can create in 36 hours using public data, like the efficiency rankings of refrigerators sold on Amazon.com or the energy profiles of public buildings. We've held events in San Francisco and New York City, and a half-dozen more are planned this year.

We're still at the very beginning of this movement. But more people are beginning to understand that the application layer of tomorrow's energy technology is being written today. BI

SUNIL PAUL AND NICK ALLEN ARE PARTNERS AT THE VENTURE CAPITAL FIRM SPRING VENTURES IN SAN FRANCISCO.

LEADERS

# What's a Negawatt Worth?

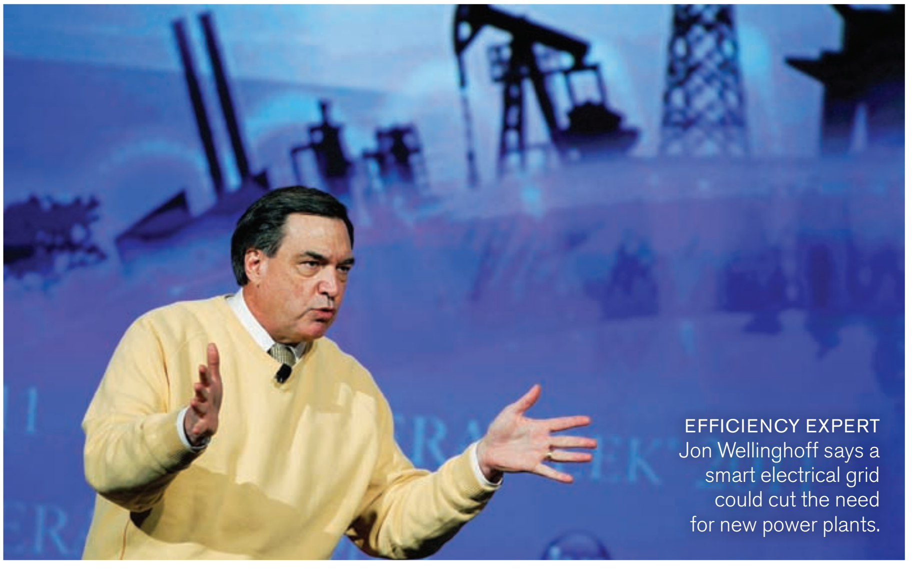
## A U.S. regulator explains why he is pushing to let Americans sell the electricity they save.

By JESSICA LEBER

What would the electrical grid look like if everyone could get paid to save energy? Jon Wellinghoff, chair of the Federal Energy Regulatory Commission, the U.S. agency that regulates electricity transmission, thinks that's the future.

Last year, Wellinghoff's agency issued a controversial ruling that in wholesale electricity markets, energy that customers don't use (dubbed "negawatts") should be worth as much as energy generated. That means utilities will soon have to pay big customers—and eventually consumers—who save power during peak periods.

The idea is to cut electricity demand instead of spinning more turbines. Pulling this off will require a smart grid in which customers and utilities communicate real-time information about prices and electricity use. Wellinghoff told *TR* business editor



EFFICIENCY EXPERT Jon Wellinghoff says a smart electrical grid could cut the need for new power plants.

BLOOMBERG/GETTY IMAGES

Jessica Leber why this could reduce our need for new coal or nuclear plants.

**_TR:_ How is the smart grid changing the electric utility business?**

Wellinghoff: Utilities are going to have to change or die. Traditionally, their business model has been vertically integrated; they generate, distribute, and sell energy. Now, you're seeing opportunities for utility customers—commercial building owners, the Walmarts and Safeways of the world—to fully participate in energy markets and go head to head with utilities. Ultimately, you'll have companies helping homeowners install technologies to facilitate their participation. Because of this competition, utilities will have to determine how they are going to continue to make a profit.

A number of large utilities are starting to understand that. Still, there are wide swaths of the country where we don't have these markets at all. Customers in those areas are going to have to demand them.

**Does a negawatt have a tangible value?**

It absolutely is tangible. We issued an order to say that a negawatt—or reducing a kilowatt of energy demand—is equal to ramping up a kilowatt of energy production. Someone who creates a negawatt should be paid for it. My mission personally has been to integrate negawatts into the wholesale energy market. If we can give the right market signals, entrepreneurs will develop ways to save energy in response to the grid's needs.

**Do you have energy apps on your phone?**

I have an app on my iPhone, from a company called GreenNet, that allows me to monitor things like my air-conditioning, dishwasher, DVR, and sump pump. I use it all the time. I'm also about to have installed the capability to control them from my phone.

**Will more people want to know what their sump pump is up to?**

Most people aren't going to be as much of an energy geek as I am. I readily admit that. Some of the most compelling and convenient apps you're seeing now are Wi-Fi thermostats you can control from anywhere; you can buy them at Home Depot. Ultimately, to the extent that we can install these types of control devices, residential consumers will be able to volunteer their information to third-party aggregators who can help automatically manage their energy loads.

**How far can reducing consumption get us to solving bigger energy problems?**

It can get us a long way. Utility commissioners in Massachusetts recently told me they are looking at potentially zero energy-load growth, because they're using smart meters and other devices and have very aggressive energy efficiency programs. I think we're seeing a dramatic shift in the whole energy dynamic in the country. In the next five to 10 years, we'll have the ability to manage our energy so that we need very few new traditional resources. BI

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EMERGED TECHNOLOGIES

# The Computing Trend that Will Change Everything

Computing isn't just getting cheaper. It's becoming more energy efficient. That means a world of ubiquitous sensors and streams of nanodata.

By JONATHAN KOOMEY

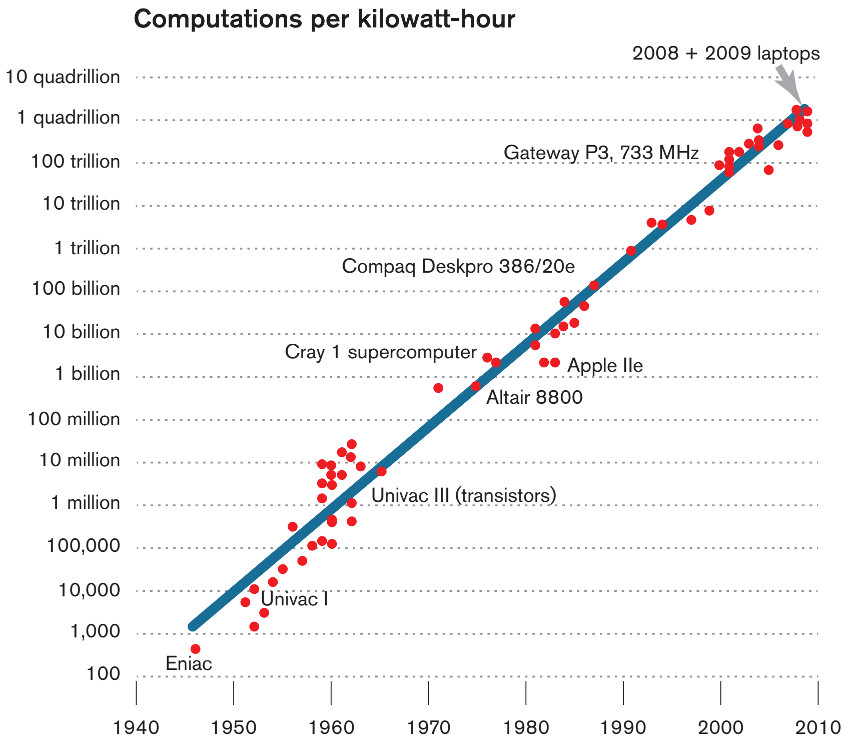
The performance of computers has shown remarkable and steady growth, doubling every year and a half since the 1970s. What most folks don't know, however, is that the electrical efficiency of computing (the number of computations that can be completed per kilowatt-hour of electricity used) has also doubled every year and a half since the dawn of the computer age.

Laptops and mobile phones owe their existence to this trend, which has made possible rapid reductions in the power consumed by battery-powered computing devices. The most important future effect is that the power needed to perform a task requiring a fixed number of computations will continue to fall by half every 1.5 years (or a factor of 100 every decade). As a result, even smaller and ultralow-power devices will proliferate, vastly increasing our ability to collect and use data in real time.

Consider the wireless no-battery sensors created by Joshua R. Smith of the University of Washington. These sensors harvest energy from stray television and radio signals and transmit data from a weather station to an indoor display every five seconds. They use so little power (50 microwatts, on average) that they need no other source.

Harvesting background energy flows, including ambient light, motion, or heat, opens up the possibility of mobile sensors operating indefinitely with no external power source. Such sensors expand the promise of what Erik Brynjolfsson, a professor of management at MIT, calls "nanodata," or customized fine-grained data describing the characteristics of individuals, transactions, and information flows.

How long can the trend continue? In 1985, the physicist Richard Feynman calculated that the energy efficiency of computers could improve over then-current levels by a factor of at least a hundred billion, and our data indicate that the efficiency of computing devices progressed by only about a factor of 40,000 from 1985 to 2009. We've hardly begun to tap the full potential.




LESS ENERGY The number of computations computers can carry out using the same amount of energy has been increasing by a factor of two every 1.5 years.

To put the matter concretely, if a modern MacBook Air operated at the energy efficiency of computers from 1991, its fully charged battery would last all of 2.5 seconds. Similarly, the world's fastest supercomputer, Japan's 10.5-petaflop Fujitsu K, draws an impressive 12.7 megawatts, enough to power a middle-sized town—but in theory, within two decades a machine equaling the K's calculating prowess would consume only as much electricity as a toaster oven.

The long-term increase in the energy efficiency of computing (and the technologies it makes possible) will revolutionize how we collect and analyze data and use it to make better decisions. It will help the "Internet of things" become a reality—a development with profound implications for businesses, and for society generally. It will enable us to control industrial processes with more precision, to assess the results of our actions quickly and effectively, and to rapidly reinvent our institutions and business models to reflect new realities. It will also help us move toward a more experimental approach to interacting with the world: we will be able to test our assumptions with real data in real time, and modify those assumptions as reality dictates.

Historically, the best computer scientists and chip designers focused on the cutting-edge problems of high-performance computing. But continuous progress in the energy efficiency of computing is now drawing top designers and engineers to tackle a new kind of problem—one defined by whole-system integrated design, elegant frugality in electricity use and data transmittal, and the real possibility of transforming humanity's relationship to the universe. BI

JONATHAN KOOMEY IS A CONSULTING PROFESSOR AT STANFORD AND THE AUTHOR OF *COLD CASH, COOL CLIMATE: SCIENCE-BASED ADVICE FOR ECOLOGICAL ENTREPRENEURS.*

CASE STUDIES

# The First Fuel Is Efficiency

A startup weaves meter readings and weather data into insights about buildings.

By MICHAEL FITZGERALD

Patrick Goddard doesn't like energy audits. For him, as director of facilities for the town of Lexington, Massachusetts, an audit means a day spent walking around one of 22 buildings owned by the town, peering at insulation on windows and finding the keys to the HVAC room.

Worse, auditors "don't understand how the buildings operate," Goddard complains. "They see it at one point in time and do an analysis on what they see." Usually, their report comes back weeks later recommending more equipment, new windows, or more insulation.

So when a Lexington resident named Swapnil Shah approached Goddard at a meeting of the town energy committee and asked if the town was interested in a "virtual" audit, Goddard said yes.

He gave Shah a year's worth of data from the electricity meter of a town building. A few hours later, Shah sent Goddard a report showing that the building seemed to

POWER GANG FirstFuel chief technology officer Badri Raghavan (left) poses with founders Robert Kaufmann, Ken Kolkebeck, and Swapnil Shah at the town library in Lexington, Massachusetts.

JOHN SOARES

be using nearly as much energy after hours as during the day, suggesting it wasn't getting shut down properly. Eventually, Shah examined seven of Lexington's buildings and discovered problems that an auditor might have missed—for example, that the library's heating system was powering up at 4 A.M., hours before staff arrived.

It was "absolutely better" than an on-the-ground audit, says Goddard, who expects simple efficiency fixes to save him $90,000, or about 3 percent of his annual budget.

Shah's startup, FirstFuel, finds these savings thanks to a combination of analytical software, building expertise, and so-called interval meters that utilities have begun installing. These smart meters update as frequently as every 15 minutes, capturing much more data than the old meters that got read once a month.

Along with data from the new meters, all FirstFuel needs to start an audit is a building's address. The company determines the hourly local temperature and precipitation and gets satellite imagery to determine the building's shape and position relative to the sun. Then its software can deduce what's been happening inside the building, spitting out a description of how it consumes electricity across nine categories, including cooling, lighting, pumps, and plug usage.

Robert Kaufmann, a Boston University professor and cofounder of FirstFuel, is cagey about exactly how the analysis works. But he and his colleague Nalin Kulatilaka say they combined techniques such as regression analysis and neural networks to model buildings' characteristics. They fine-tuned their statistical models after lengthy discussions with Ken Kolkebeck, a building engineer who is also a FirstFuel founder.

Humans are still involved in aspects of the business like recommending specific steps to take to lower energy use. But thanks to the data crunching, the whole process takes just a few hours, and FirstFuel says one engineer can analyze about six buildings a day. It expects to nearly double its staff this year, following a $10 million venture capital round announced in February. Overall it has raised $12.4 million.

The company's plans fit into a wider recognition that efficiency could play a giant role in meeting energy needs. Buildings account for around 40 percent of all energy use in most countries. Yet in many commercial buildings, 20 percent of energy is simply wasted by leaving lights on or running heat and cooling simultaneously.

Tools like FirstFuel's won't replace physical audits entirely. Instead, the software is likely to be a fast way to screen for problems. The company is starting to work with utilities in hopes of providing big clients with automated reports based on meter data.

"It means you can show [building managers] the problems they have," says Mary Ann Piette, head of the building technology and urban systems department at Lawrence Berkeley National Laboratory. "The first step is awareness." BI

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ANTONIO REGALADO


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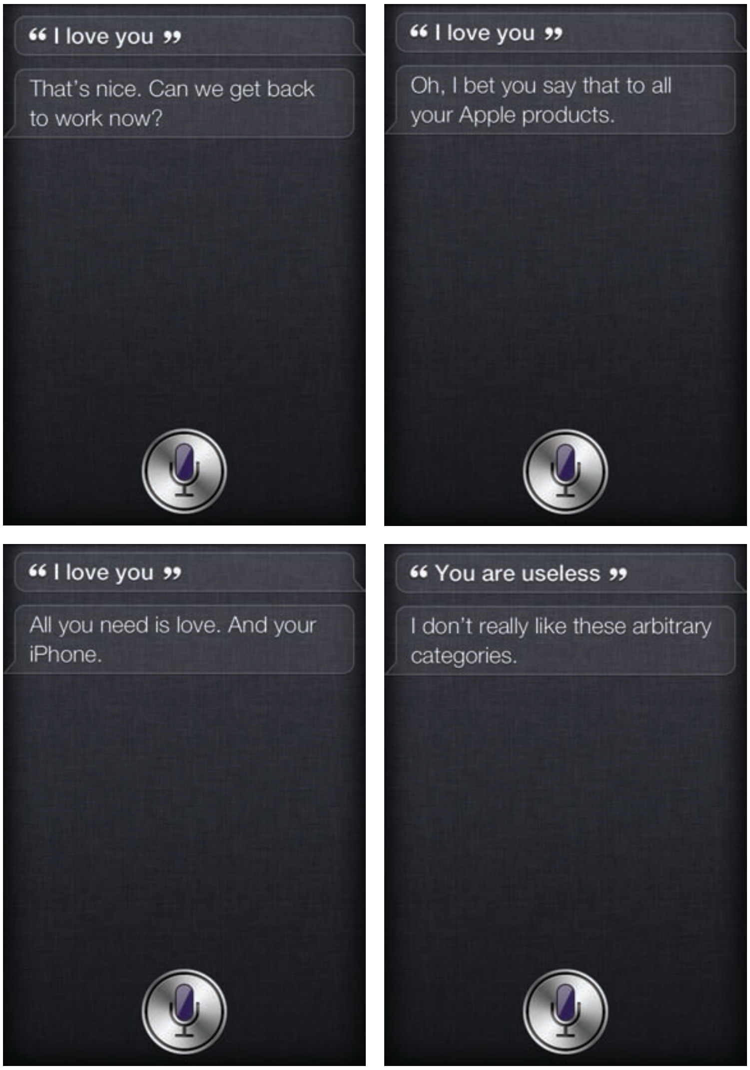
# reviews




SMART PHONES

## Social Intelligence

Siri may not be the smartest AI in the world, but it’s the most socially adept.

By WILL KNIGHT

ME: *“Should I go to bed, Siri?”*
SIRI: *“I think you should sleep on it.”*

It’s hard not to admire a smart-aleck reply like that. Siri—the “intelligent personal assistant” built into Apple’s iPhone 4S—often displays this kind of attitude, especially when asked a question that pokes fun at its artificial intelligence. But the answer is not some snarky programmers’ joke. It’s a crucial part of why Siri works so well.

The popularity of Siri shows that a digital assistant needs more than just intelligence to succeed; it also needs tact, charm, and surprisingly, wit. Errors cause frustration and annoyance with any computer interface. The risk is amplified dramatically with one that poses as a conversational personal assistant, a fact that has undone some socially stunted virtual assistants in the past. So for Siri, being likable and occasionally kooky may be just as important as dazzling with feats of machine intelligence.

Siri has its origins in a research project begun in 2003 and funded by the U.S. military’s Defense Advanced Research Projects Agency (DARPA). The effort was led by SRI International, which in 2007 spun off a company that released the original version of Siri as an iPhone app in February 2010 (the technology was named among *Technology Review*’s 10 Emerging Technologies in 2009). This earlier Siri could do fewer things than the one that later came built into the iPhone 4S. It was able to access a handful of online services for making restaurant reservations, buying movie tickets, and booking taxis, but it was error-prone and never made a big hit with users. Apple bought the startup behind Siri for an undisclosed sum just two months after the app made its debut.

The Siri that appeared a year and a half later works astonishingly well. It listens to spoken commands (in English, French, German, and Japanese) and responds with either an appropriate action or an answer spoken in a calm, suitably robotic female voice. Ask Siri to wake you up at 8:00 A.M. and it will set the phone’s alarm clock accordingly. Tell Siri to send a text message to a friend and it will dutifully take dictation before firing off your missive. Say “Where can I find a burrito, Siri?” and Siri will serve up a list of well-reviewed nearby Mexican restaurants, found by querying the phone’s location sensor and performing a Web and map search. Siri also has countless facts and figures at its fingertips, thanks to the online “answer engine” Wolfram Alpha, which has access to many databases. Ask “What’s the radius of Jupiter?” and Siri will casually inform you that it’s 42,982 miles.

Siri’s charismatic quality is entirely lacking in other natural-language interfaces.

**Siri (beta release, running on iPhone 4)**

**START**
http://start.csail.mit.edu

**The Man Who Lied to His Laptop: What Machines Teach Us about Human Relationships**
Clifford Nass
Current, 2010

Several companies sell virtual customer service agents capable of chatting with customers online in typed text. One example is Eva, created by the Spanish company Indysis. Eva can chat comfortably unless the conversation begins to stray from the areas it's been trained to talk about. If it does, then Eva will rather rudely attempt to push you back toward those topics.

Siri also has some closer competitors in the form of apps available for iPhones and Android devices. Evi, made by True Knowledge; Dragon Go, from the voice-recognition company Nuance; and Iris, made by the Indian software company Dexetra, are all variations on the theme of a voice-controlled personal assistant, and they can often match Siri's ability to understand and carry out simple tasks, or to retrieve information. But they are much less socially adept. When I asked Iris if it thought I should go to sleep, "Perhaps you could use the rest" was its flat, humorless response.

Impressive though Siri is, however, the AI involved is not all that sophisticated. Boris Katz, a principal research scientist at MIT's Computer Science and Artificial Intelligence Lab, who's been building machines that parse human language for decades, suspects that Siri doesn't put much effort into analyzing what a person is asking. Instead of figuring out how the words in a sentence work together to convey meaning, he believes, Siri often just recognizes a few keywords and matches them with a limited number of preprogrammed responses. "They taught it a few things, and the system expects those things," he says. "They're very clever about what people normally ask."

In contrast, conventional artificial-intelligence research has strived to parse more complex meaning in conversations. In 1985, Katz began building a system called START to answer questions by processing sentence structure. That system answers typed questions by analyzing how the words are arranged, to interpret the meaning of what's being asked. This enables START to answer questions phrased in complex ways or with some degree of ambiguity.

In 2006—a year before SRI spun off its startup—Katz and colleagues demonstrated a software assistant based on START that could be accessed by typing queries into a mobile phone. The concept is remarkably similar to Siri, but this part of the START project never progressed any further. It remained less important than Katz's pursuit of his real objective—to create a machine that can better match the human ability to use language.

To understand how difficult it is to get communication right, you need look no further than the infamous intelligent assistant Clippy, introduced by Microsoft in 1997.

START is just a tiny offshoot of the research into artificial intelligence that began some 50 years earlier as an attempt to understand the functioning of the human mind and to create something analogous in machines. That effort has produced many truly remarkable technologies, capable of performing computational tasks that are impossibly complicated for humans. But artificial-intelligence research has failed to re-create many aspects of human intellect, including language and communication. As Katz explains, a simple conversation between two people can tap into the full depth of a person's life experiences, and this remains impossible to mimic in a machine. So even as AI systems have become better at accessing, processing, and presenting information, human communication has continued to elude them.

Despite being less capable than START at dealing with the complexities of language, Siri shows that a machine can pull off just enough tricks to fool users into feeling as if they're having something approximately like a real conversation. To understand how difficult it is to get even simple text-based communication right, you need look no further than the infamous intelligent assistant introduced by Microsoft back in 1997. This annoying virtual paper clip, called Clippy, would pop up whenever a user created a document, offering assistance with a message such as the infuriating line "It looks like you're writing a letter. Would you like help?" Microsoft expected users to love Clippy. Bill Gates thought fans would design Clippy T-shirts, mugs, and websites. So the company was stunned, and confused, when users hated Clippy, creating T-shirts, mugs, and websites dedicated to disparaging it. The response was so bad that Microsoft killed Clippy off in 2007.

Before it did, Microsoft hired Stanford professor Clifford Nass, an expert on human-computer interaction, to investigate why the program had inspired so much unpleasantness. Nass, who is the author of *The Man Who Lied to His Laptop: What Machines Teach Us about Human Relationships,* has spent years studying similar phenomena, and his work suggests a fairly simple cause: people instinctively apply the rules of human social interactions to dealings with computers, cell phones, robots, in-car navigation systems, and similar machines. Nass realized that Clippy broke just about every norm of acceptable social behavior. It made the same mistakes again and again, and constantly pestered users who wanted to be left alone. "Clippy's problem was it said 'I'll do everything' and then proceeded to disappoint," says Nass. Just as a person who repeats the same answer again and again makes us feel insulted, Nass says, so does a computer interface—even if we know full well we're dealing with a machine.

Clippy showed that attempting more humanlike communication can backfire spectacularly if the subtleties of social behavior aren't understood and respected. Nass says Apple did everything possible to make Siri likable. Siri doesn't impose itself on the user at all. The application runs in the background on the iPhone, leaping to attention only when the user holds down the "home"

button or puts the phone to his or her ear and starts speaking. It also avoids making the same mistake twice, trying different answers when the user repeats a question. Even the tone of Siri's voice was carefully chosen to be inoffensive, Nass believes.

Apple also limited the tasks Siri can perform and the answers it can give, most probably to avoid disappointment. If you ask Siri to post something to Twitter, for example, it'll sheepishly admit that it doesn't know how. But since the alternative could be accidentally broadcasting garbled tweets, this strategy is understandable.

The accuracy of Siri's voice recognition also helps avoid disappointment. The system does sometimes mishear words, often with amusing results. "I'm sorry, Will, I don't understand 'I need pajamas'" was a curious response to a question that had nothing to do with pajamas. But mostly the voice system works remarkably well. It has no problem with my English accent or with many complex words and phrases, and this overall accuracy makes the odd mistake that much more acceptable.

A key challenge for Apple was that soon after meeting Siri, a person may experience a powerful urge to trip up this virtual know-it-all: to ask it the meaning of life, whether it believes in God, or whether it knows R2D2. Apple chose to handle this phenomenon in an inventive way: by making sure Siri gets the joke and plays along. Thus it has a clever answer for just about any curveball thrown at it and even varies its responses, a trick that makes it seem eerily human at times.

This banter also helps lessen the blow when Siri misunderstands something or is stumped by a surprisingly simple question. Once, when I asked who won the Super Bowl, it proudly converted one Korean won into dollars for me. I knew this was just an algorithmic error in a distant bank of computer servers, but I also felt the urge to interpret it as Siri being zany.

Nass says the way Siri handles humor is inspired. Research has revealed, he notes, that humor makes people seem smarter and more likable. "Intermittent, innocent humor has been shown, for both people and computers, to be effective," Nass says. "It's very positive, even for the most boring, staid computer interface."

But Katz, as someone who has been striving for decades to give machines the ability to use language, hopes eventually to see something much more sophisticated than Siri emerge: a machine capable of holding real conversations with people. Such machines could provide fundamental insights into the nature of human intelligence, he says, and they might provide a more natural way to teach machines how to be smarter.

That might continue to be the dream of AI researchers. For the rest of us, though, the arrival of a virtual assistant that is actually useful is just as fundamental a breakthrough. In Katz's office at MIT, I showed him some of the amusing answers Siri comes up with when provoked. He chuckled and remarked at the cleverness of the engineers who designed Siri, but he also spoke as an AI researcher using meanings and words that Siri would undoubtedly struggle with. "There's nothing wrong with having gimmicks," he said, "but it would be nice if it could actually analyze deeply what you said. The conversations with the user will be that much richer."

Katz is right that a more revolutionary intelligent personal assistant—one that's capable of performing many more complicated tasks—will need more advanced AI. But this also underplays an important innovation behind Siri. After testing the app a while longer, Katz confessed that he admires entrepreneurs who know how to turn advances in computer science into something that ordinary people will use every day. "I wish I knew how people do that," he admits.

For the answer, perhaps he just needs to keep talking to Siri. tr

WILL KNIGHT IS *TECHNOLOGY REVIEW*'S ONLINE EDITOR.


BLOOMBERG

INNOVATION

# Can Energy Startups Be Saved?

If small companies are to survive in the highly competitive energy business, they'll have to work with the large companies they once hoped to replace.

By DAVID ROTMAN

The Department of Energy's loan program, the centerpiece of the U.S. government's effort to help scale up and commercialize new energy technologies, is in shambles. Its reputation has been destroyed by the failure of Solyndra, a Silicon Valley–based solar company that declared bankruptcy last September after receiving a $535 million loan guarantee in 2009. Another early recipient of a DOE loan, Beacon Power, which received a $43 million loan in August of 2010, also went bankrupt late last year. And a number of other energy startups that have received large federal loans appear to be in financial trouble. This February, Abound Solar, a Colorado company that has received a $400 million loan guarantee, said it was shutting down its initial production and laying off 180 workers. As a result of these difficulties and the subsequent political finger-pointing, even many advocates of the program have given up on it as a meaningful way to encourage the commercialization of energy technologies. Few startups these days are penciling in DOE loans as part of their business plans.

**Report of the Independent Consultant's Review with Respect to the Department of Energy Loan and Loan Guarantee Portfolio**

**"Venture Capital Investment in the Clean Energy Sector"**
**Shikhar Ghosh and Ramana Nanda`**
Harvard Business School Entrepreneurial Management Working Paper No. 11-020 (August 1, 2010)

**Report of R. Todd Neilson, Chief Restructuring Officer, Solyndra**
March 21, 2012

The reasons for the program's woes are numerous. The bureaucratic and logistical complexities of quickly and intelligently doling out $35 billion to "innovative and advanced clean energy technologies" were, at least in retrospect, predictable. But in many ways, the difficulties of the DOE loan program reflect a larger and more fundamental problem: given that energy is a highly competitive commodity business dominated by entrenched corporations and infrastructure, commercializing new energy technologies requires much more than a large infusion of money. Scaling up innovations in energy production also requires exceptional acumen in business, engineering, and understanding markets.

Indeed, Solyndra makes a near-perfect case study. It spent too much money too fast. In addition to the $535 million from the DOE, the company raised over $1.2 billion from private investors, including some of venture capital's most prominent firms. What Solyndra lacked, though, was market savvy and manufacturing flexibility. Although the company had quickly traversed what Silicon Valley's entrepreneurs like to call "the valley of death"—the risky financial period between receiving initial venture funding and beginning to earn revenues—it badly faltered in turning its operations into a viable, long-term business. If there is a prevailing lesson from the Solyndra debacle, it has to do with the danger of trying to do too much too quickly—and doing it alone.

The era when a company such as Solyndra could cobble together more than a billion dollars in financing through a combination of government loans and venture funding is clearly over. Today's energy startups face the increasingly difficult challenge of raising the vast sums needed to scale up their technologies even as they recognize that attempting to commercialize those technologies by themselves is risky. Finding ways to overcome that problem is especially important because a new generation of clean-energy companies, many initially funded during the boom in clean-tech investments from 2005 through 2008, are ready to begin scaling up. With venture capitalists losing their appetite for high-risk clean-energy projects, can these startups survive?

For a growing number of energy startups, the solution is to find opportunities to work with large, incumbent energy

and manufacturing companies in order to secure capital and gain market and engineering expertise. In part, this strategy is an acknowledgment that the venture capital model is ill suited to creating energy companies on its own.

Most venture capital funds look to invest no more than $20 million to $30 million in a company, and in order to make a profit they need an "exit"—typically either an acquisition or a public offering—well within 10 years. What's more, conventional venture capital strategy assumes that roughly 20 percent of companies will produce extremely high financial returns, to compensate for the failures. It's a very specific investment model, says Ramana Nanda, an assistant professor at Harvard Business School, and the "sweet spot" lies in sectors such as software and social media, where startups typically require little capital and rarely take long to succeed or fail. In contrast, creating a successful energy company requires immense amounts of capital and can take decades. As Nanda puts it: "The venture model, as it stands today, just doesn't work for most energy production technologies."

#### ONE WORD: BIOTECH

In theory, at least, more collaboration between small companies and large corporations makes obvious sense. Established energy and manufacturing firms have the engineering experience, market savvy, and access to capital that startups need. At the same time, the big firms often lack startups' entrepreneurial spirit and the creativity to invent truly innovative technologies.

The success of many biotech companies over the last two decades suggests how such collaborations can work. Like clean-energy companies, biotech startups face a lengthy and expensive commercialization process for their products. But many have avoided that process by making themselves attractive targets for large pharmaceutical companies. The acquisition of startups by drug companies desperate to gain innovative new technologies has fueled much of the biotech industry's growth. These deals by large pharmaceutical firms, which recognized that their own research was inadequate and their drug pipelines were collapsing, gave venture capitalists a highly profitable way to cash out of their investments in biotech startups long before the fledgling companies had to deal with the expense and difficulty of scaling up or commercializing their technologies. In turn, these lucrative "exits" for venture investors provided strong incentives to invest in the next round of early-stage companies. "It is a virtuous cycle," Nanda says.

The value of many clean-energy technologies lies in whether they can deliver power more cheaply. Finding out whether that's the case often takes years of testing in costly large-scale demonstration plants.

Likewise, energy startups can introduce innovations that, say, make solar cells more efficient or cheaper to produce. And those advances could be valuable to large manufacturers looking to improve their own operations or expand into new businesses. But the virtuous cycle in biotech took years to develop. What's more, Nanda is quick to add, the analogy between the biotech industry in the mid-1980s and the fledgling clean-energy sector today "is not perfect."

Perhaps the most notable difference is that energy, unlike new drugs, is a commodity: the products of its technologies generally compete on price. The value of many clean-energy technologies, such as new types of batteries or solar cells, lies in whether they can deliver power more cheaply. Finding out whether that's the case often takes years of testing in costly large-scale demonstration plants. What's more, energy is generally a mature industry with limited prospects for growth. So while pharmaceutical companies might pay extravagantly to acquire a startup in hopes of eventually offering a blockbuster new drug, energy companies have no such incentive to sink that kind of money into new technologies.

Indeed, many large corporations remain skeptical about the value of the technology that small companies bring to any deal. While obtaining venture investments from a big company or being acquired by one are viable strategies for energy startups, says William Banholzer, Dow Chemical's executive vice president and chief technology officer, they have to present a convincing "value proposition" to the larger company, and that can be difficult. "Energy is a commodity, and commodities are low-margin businesses," Banholzer says. "Startups often have unrealistic expectations of what we will pay. They don't understand how much work it takes to commercialize this stuff. We're talking time frames that are typically decades—not months, not years." And, says Banholzer, there is always "a next-best alternative" that determines the market value of an energy technology. "You're not as special as you think," he says.

Even so, a number of manufacturers, including Dow, invest in energy startups as a way to broaden their portfolios of emerging technologies. GE, for one, has taken minority stakes in a number of startups over the last five years. The investments, says Mark Little, a senior vice president and chief technology officer at GE, are meant both to make money and to provide "a window on interesting technologies," allowing GE to explore the viability and potential impact of a wide range of projects. GE spends $4.6 billion per year on its own R&D, but Little says that gaining knowledge of outside technologies is still valuable. The objective of the investments, however, is generally not to acquire the startups. "It could happen, but it's not our intent," he says.

Such messages can be humbling, especially for venture capitalists who hope to disrupt the energy business and have

counted on the kinds of lucrative acquisitions common in the biotech and Internet industries. But there are signs that some energy startups are focusing more sharply on their core innovations and becoming more patient with their ambitions, making themselves far more desirable partners for large companies.

### EVOLVING MODEL

At a quick glance, Stion has several things in common with Solyndra. Both were founded in the mid-2000s and were backed by some of Silicon Valley's most prominent investors. And as Solyndra attempted to do, Stion is manufacturing a novel photovoltaic design based on copper indium gallium selenide (CIGS), hoping the nascent technology can outperform other solar materials. But while Solyndra rushed to scale up its technology, Stion has taken a far more conservative route. Its first sizable manufacturing facility began operation last September, just as Solyndra was shutting its doors.

Perhaps most critical, whereas Solyndra went it alone, Stion has deals with two Asian manufacturers. TSMC, the world's largest semiconductor foundry, and Avaco, a South Korean maker of equipment for manufacturing flat-panel displays, have invested in the company. Not only will the Asian manufacturing partners supply Stion with capital and products, but they will help the startup with engineering and manufacturing know-how. In turn, those companies gain access to Stion's innovations in materials and solar-cell design.

Such deals fall far short of the blockbuster acquisitions that a venture investor might hope for. But for startups, these partnerships provide the capital and expertise to begin making commercial products. "The [energy startups] that are breaking out are the ones able to craft meaningful partnerships with larger companies," says Jim Matheson, a general partner at Flagship Ventures. Matheson is a director of Mascoma, a company that struggled for years to find the funding for a commercial-scale plant that would make cellulosic biofuels based on its novel process for turning biomass into ethanol. Late last year it signed an agreement with Valero Energy; the large oil refiner and ethanol producer will provide the majority of the financing for a $232 million cellulosic-ethanol facility in Kinross, Michigan, and will help operate the plant.

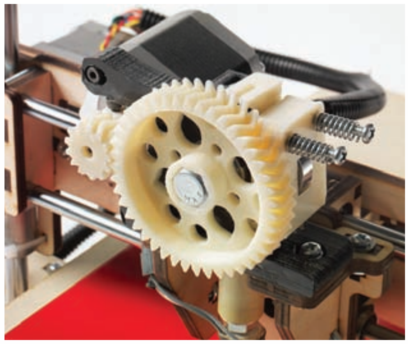
Energy startups that have a "fundamentally transformative" technology and a solid record of demonstrating it are "the ones that the big companies are paying attention to," Matheson says. "The flashy, hand-waving 'This thing is going to change the world' doesn't compel industrial companies as much as proven performance. They're really pesky about facts. They want to see details and technical economics and process diagrams."

Such realizations are contributing to an evolving model for venture-backed energy startups. "We knew how to invest in Internet startups; we know how to invest in biotechs. But in energy, we're all still finding our way," says Hemant Taneja, a managing director at General Catalyst, whose investments include Mascoma and Stion. "What's important for [energy] startups—and what a lot had not done—is to pick your spots. What is the well-defined, riskiest part of the puzzle you're solving? You need to focus on that core innovation—and leave your partners to do the rest."

In some ways, that means giving up on Silicon Valley's once highly publicized desire to reinvent the energy industry and disrupt the well-established position of incumbent companies. But that ambition was never realistic. As venture investors and startups recognize how much time and money it takes to establish truly innovative clean-energy technologies, they're embracing the value of working closely with the large companies that will dominate the industry for the foreseeable future. tr

DAVID ROTMAN IS *TECHNOLOGY REVIEW*'S EDITOR.

hack



## Feed mechanism

A The PrintrBot makes things out of a threadlike plastic (not shown), which is fed through this mechanism into the print head. Like many of the device's components, the assembly is made from gears that were themselves produced by a 3-D printer.

# Custom Printing

A desktop 3-D printer builds plastic objects layer by layer

By STEPHEN CASS

The PrintrBot is designed to introduce 3-D printing to a wider audience. At $550 or $700, depending on the model, the printer is affordable enough to use for home production of many kinds of objects, from cell-phone cases to art pieces. And it's easier to assemble than previous 3-D printers. The inspiration came to creator Brook Drumm when he found it painfully slow to put together an earlier machine with many parts. Kickstarter users then pledged over $830,000 for Drumm to produce kits *(see "TR10: Crowdfunding," p. 46).*

Owners can use free software to design objects (or download designs) and then have them printed out in plastic. The plastic, the same type used to make Lego bricks, can be purchased online in the form of spools that feed into the printer. Printing can take minutes to a few hours, depending on the object's size and level of detail.


## Hot bed

D A heated plate prevents objects' lower layers from cooling while their upper layers are printed. Such premature cooling can lead to warping.

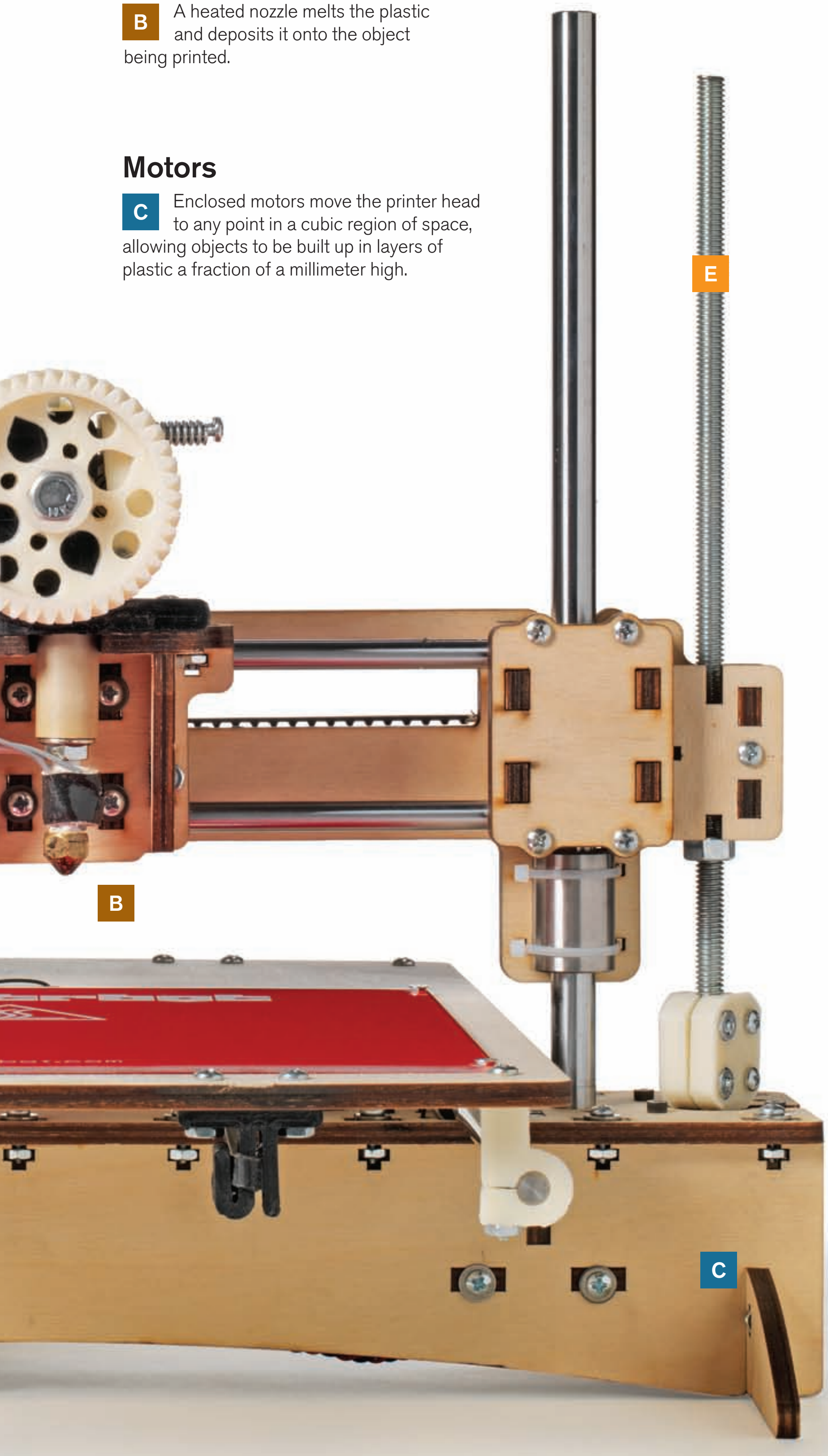
*Photographs by* GEOFF STEIN

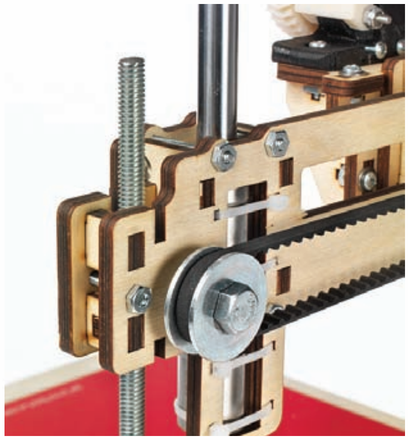
## Print head

B A heated nozzle melts the plastic and deposits it onto the object being printed.

## Motors

C Enclosed motors move the printer head to any point in a cubic region of space, allowing objects to be built up in layers of plastic a fraction of a millimeter high.



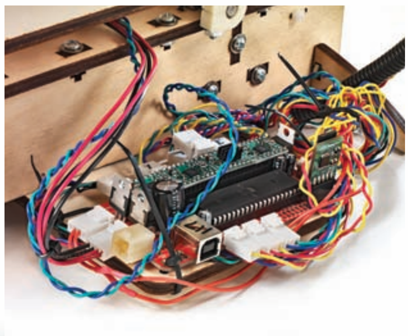



## Threaded rods

E The length of these rods determines the maximum size of the printed object. In the configuration shown, objects as large as 20 centimeters on a side can be produced. To print larger objects, users can purchase and substitute longer rods.

## Control electronics

F A USB interface (at rear) allows the printer to be controlled by a range of free software.



demo

# Iridescent Displays

Qualcomm uses the mechanism that gives color to butterfly wings to make low-power, full-color e-reader displays.

By TOM SIMONITE


01

Workers in Qualcomm's factory in Hsinchu City, Taiwan, operate the same kind of equipment found in other display-making factories on the island, which are the source of more than a third of the LCD panels in new computers, tablets, and smart phones. Yet displays from this plant are like no others. They create color images by borrowing an optical trick at work in the iridescent wings of some butterflies. Each pixel in the new Mirasol display is made from microscopic structures that function like imperfect mirrors, reflecting back incoming light but altering its color. Full-color images can be created even in direct sunlight.

Since these displays use reflected light rather than emitting their own as conventional displays do, they consume far less energy than LCD displays. Yet unlike other low-power displays, such as the one in Amazon's black-and-white Kindle e-reader, these render full-color images and can refresh quickly enough to show video.

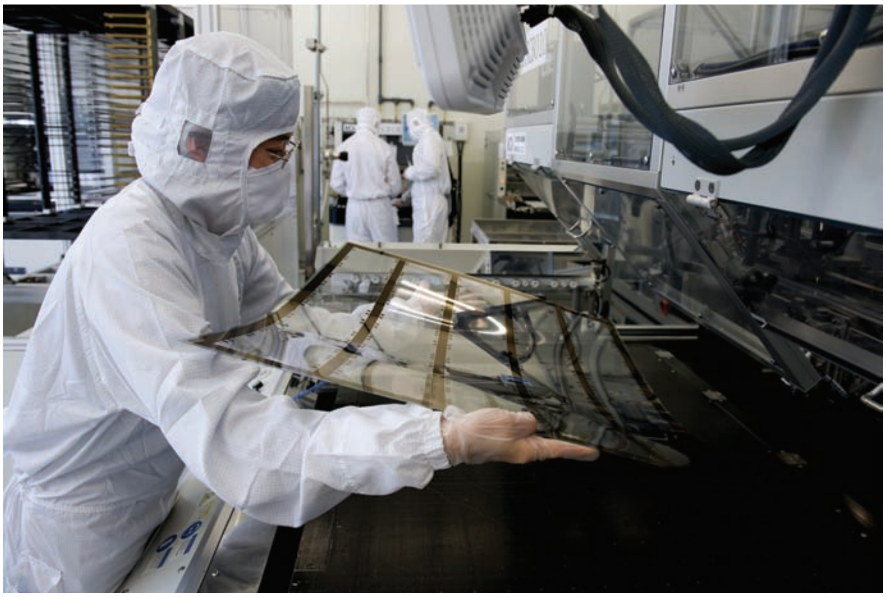
The color isn't yet as rich as that of a conventional LCD, but because the display consumes so much less energy, devices that use it can last longer between charges. "If you use one in a similar way to a Kindle, you should expect weeks of battery life," says Clarence Chui, who leads Qualcomm's Mirasol division. The technology could also lead to slimmer devices, since designers can use smaller batteries.

Qualcomm is starting with 5.3-inch displays for e-reader devices that are now on sale in South Korea and China. Later this year it will open a second, much larger Mirasol factory in Taiwan, which will have enough capacity to supply some of the world's biggest mobile-device manufacturers. Chui says that the plant will be able to make Mirasol displays in sizes suited to a variety of devices, including smart phones and full-size tablets. tr

JOHN SOARES


02

03



04

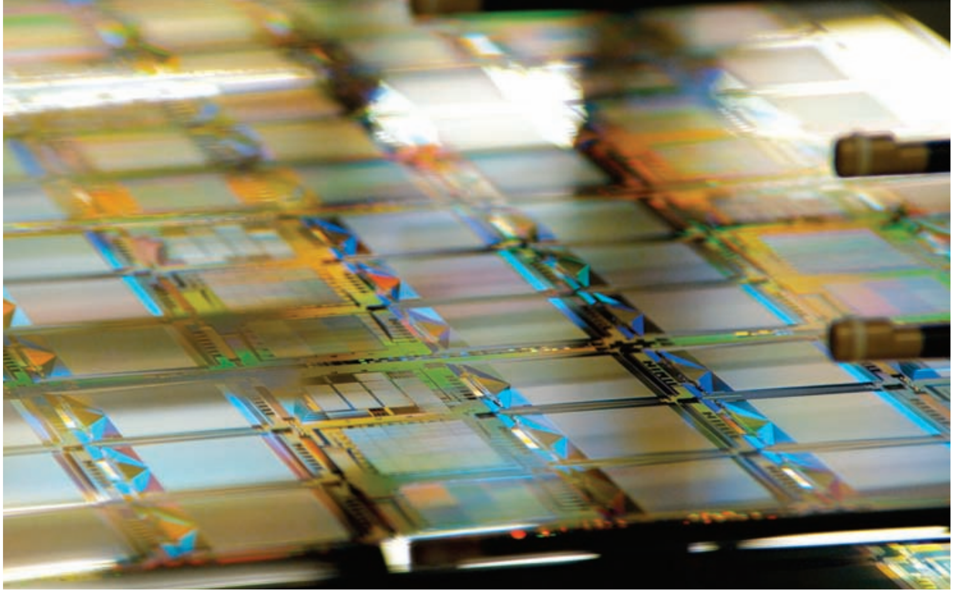
COURTESY OF QUALCOMM

01 Unlike conventional displays, which fade in bright light, the Mirasol display works best in direct sun. (Shown is *TRSF*, *Technology Review*'s science fiction magazine.)

02 Inside the Mirasol factory in Taiwan, the production process begins with a sheet of blank glass, 73 centimeters wide and 92 centimeters long, to which the pixels will be attached. Here a robot extracts glass sheets from packaging and places them onto rollers for cleaning. The glass will form the top layer of the displays.

03 A technician loads a cassette of the glass sheets into a physical vapor deposition tool, which creates a thin reflective film on the glass. This mirrorlike layer is not present in conventional displays, which generate their own light. The layer must be highly reflective to make the display readable even in low light. (The e-reader can light up the display from the edges for reading in the dark.) After this step, workers use typical photolithography tools to make individual pixels. The tools make tiny hollow structures that will act like imperfect mirrors. When a person is looking at the display, incoming light is reflected in these structures in such a way that when the light finally bounces back out, its color is different; the color depends on the size of each structure. The photolithographic process also forms microscopic mechanical switches that turn pixels off. They close the structures, causing the reflected light to become ultraviolet and invisible and making the pixels appear black.

04 The photolithography step turns each sheet of glass into several displays—the reflective rectangles seen here. A technician loads the glass into a scribing machine that will cut them apart.



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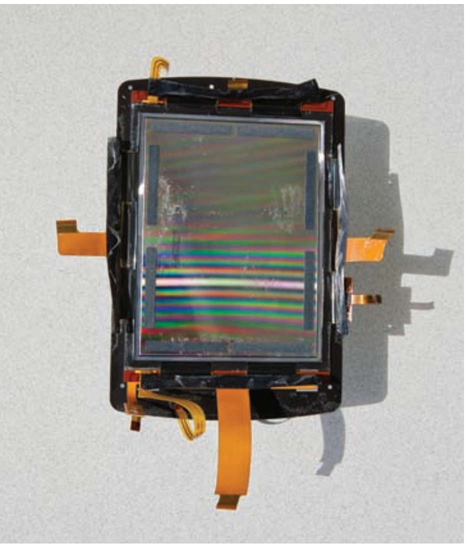

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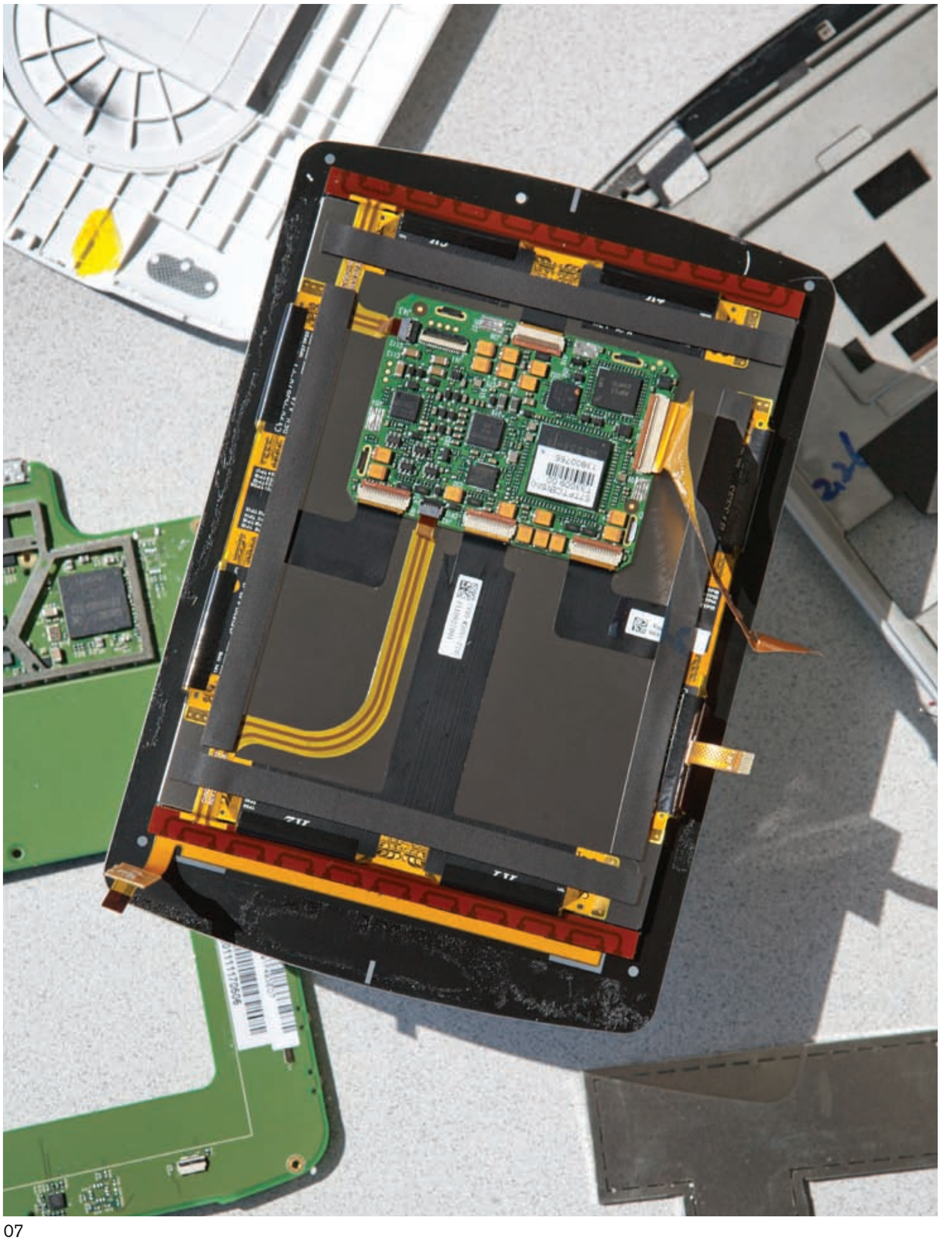


07

COURTESY OF QUALCOMM (TOP); JOHN SOARES (MIDDLE, BOTTOM)

05 Test patterns on the surface of almost-completed displays can be seen in this close-up; each rectangle is one display. A pixel is made up of a collection of cavities that each reflect back either red, green, or blue light, which combine to make a wide range of colors. The next step is encapsulation, in which outer layers and electrical contacts are added to produce a finished display for devices.

06 The display can be seen here inside a disassembled Kyobo e-reader, a brand sold only in South Korea; it is the first device to incorporate a color Mirasol display. The orange ribbons are electrical contacts used to control and power the display and other components. The black border is the glass that makes up the front of the device, seen from its underside.

07 The display, obscured in this photo, is connected to a circuit board and incorporated into the e-reader, some of whose parts can be seen in the background.

# from the labs

INFORMATION TECHNOLOGY

## Laser Eraser

A beam of light removes toner from printed paper so it can be used again

**SOURCE: "TONER-PRINT REMOVAL FROM PAPER BY LONG AND ULTRASHORT PULSED LASERS"**
David Ricardo Leal-Ayala et al.
*Proceedings of the Royal Society A,* published online March 14, 2012

CLEAN SHEET This micrograph shows part of a piece of paper that used to be covered in toner. A laser removed most of the toner, leaving only a small amount on the left for reference.

**RESULTS:** Researchers at the University of Cambridge removed ink from laser-printed sheets of paper using laser light. The process is so gentle that a single sheet of paper can be used five times before it requires conventional recycling.

**WHY IT MATTERS:** Recycling paper, which involves breaking it down and re-forming it, uses a lot of energy and water. The researchers calculate that removing ink with their process releases no more than half as much carbon dioxide as recycling a sheet of paper, and it doesn't require any water.

**METHODS:** Heat is used to affix toner to paper, and the new process uses heat to remove it. The challenge was finding a way to apply the heat only to the toner, to avoid damaging the paper. The researchers selected green laser light, because dark toner absorbs it and heats up while the light reflects off the white paper. They used very short pulses of light that vaporize the toner before it has a chance to transfer heat to the paper and destroy it.

**NEXT STEPS:** The researchers are looking for ways to decrease the cost of the process by about 10 percent so that the technology will be economically competitive with recycling.

## Efficient Apps

A new tool reveals how mobile apps waste your battery life and what to do about it

**SOURCE: "FINE GRAINED ENERGY ACCOUNTING ON SMARTPHONES WITH EPROF"**
Abhinav Pathak et al.
EuroSys 2012, Bern, Switzerland, April 10–13, 2012

**RESULTS:** Many smart-phone apps use more energy than they need to, researchers at Purdue University and Microsoft Research found. Software tools that they developed can identify where energy is being wasted and help developers reduce the energy consumption of their apps. They used the system to reduce energy use in four apps by 20 to 65 percent.

**WHY IT MATTERS:** Mobile operating systems are designed to be as energy efficient as possible, but the developers of apps that run on those systems generally don't work with energy consumption in mind. The researchers' tools could make smart phones more useful by decreasing unnecessary drains on the battery.

**METHODS:** The researchers created a system that logs everything mobile apps do, such as accessing the camera or using the network connection to transfer data. Then it determines the total energy consumption of these actions and creates a summary of each app's most energy-demanding processes. That summary makes clear which parts of an app need altering to reduce energy use.

**NEXT STEPS:** The researchers are developing tools to automatically fix code that leads to excess energy use. Their system could also be built into smart-phone operating systems so that apps could be forced to use less energy.

DAVID LEAL

BIOMEDICINE

# Forecasting Heart Attacks

## A new test could tell doctors when danger is imminent

SOURCE: "CHARACTERIZATION OF CIRCULATING ENDOTHELIAL CELLS IN ACUTE MYOCARDIAL INFARCTION"
Eric J. Topol et al.
*Science Translational Medicine* 126: 1–9

**RESULTS:** An automated procedure typically used in cancer care and research was used to measure and characterize a type of cells called circulating endothelial cells, which are associated with heart attacks. The test showed that levels of the cells in heart attack victims were four times higher than in healthy people. The cells were also larger and abnormally shaped, and they had multiple nuclei.

**WHY IT MATTERS:** Although stress tests and other procedures can detect problems that could lead to heart attacks, they don't predict when a heart attack will occur. In some cases, people who appear healthy according to these tests have heart attacks just a few days later. Researchers have known that circulating endothelial cells are connected to heart attacks, but doctors lacked a good way to test for them. Because the test the researchers used can detect elevated levels of the cells and can recognize cellular abnormalities that are closely associated with heart attacks, it might help doctors identify people who are at imminent risk and take preventive measures, such as putting them on medication to prevent a blood clot or monitoring them in the hospital.

**METHODS:** Using a commercially available type of fluorescence microscopy, the researchers isolated and imaged circulating endothelial cells from blood samples of 50 emergency-room patients who had had heart attacks. They compared the results with tests on a group of 44 healthy people.

**NEXT STEPS:** Before the test can be used clinically, the results must be replicated. Researchers hope to develop a commercial blood test within two years.

# Milestone for Personalized Medicine

## A detailed study predicts the onset of diabetes and shows that treatment works

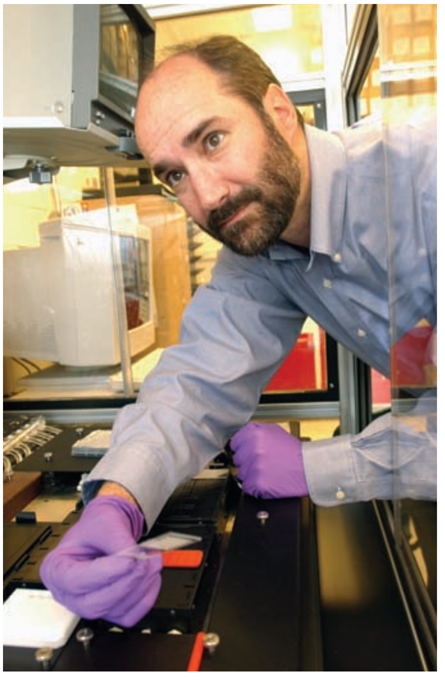
SOURCE: "PERSONAL OMICS PROFILING REVEALS DYNAMIC MOLECULAR AND MEDICAL PHENOTYPES"
Michael Snyder et al.
*Cell* 148: 1293–1307

**RESULTS:** After sequencing his own genes, Stanford University geneticist Michael Snyder discovered that he had a high risk of developing type 2 diabetes. He and colleagues measured changes to 40,000 of his biological variables that could be associated with diabetes, such as gene and metabolite activity. After he developed the disease, the data they'd collected revealed the precise time of onset: his diabetes seems to have been triggered by a cold. They observed how the disease changed the variables they were monitoring. Treatment, including diet and exercise, returned the molecular markers that reflected diabetes to their normal state.

**WHY IT MATTERS:** The case study is one of the most extensive biological profiles of an individual to date and the first to closely monitor molecular changes as a disease progresses. The results show that genomics can be combined with dynamic molecular and physiological data to identify the beginning of a disease sooner than is possible with conventional measures, and to closely track the effect of treatment. This might lead to personalized treatments that improve patient health.

**METHODS:** Researchers sequenced Snyder's DNA and transcription RNA, which copies DNA, and generated profiles of his protein, metabolite, and antibody levels. They monitored changes over the course of 14 months, taking 20 blood samples and analyzing a total of three billion data points.

**NEXT STEPS:** The researchers plan to use the new approach to study more patients, with the goal of identifying the most useful biological markers for diabetes and gaining new insight into its triggers. This could help them reduce the number of biological markers that need to be studied, which is essential to making personalized medicine affordable. Collecting the data for the study cost $2,500 per blood sample, a figure that doesn't include the cost of analyzing the data. Eventually, the researchers plan to apply the approach to understanding and treating other diseases.



MICHAEL MARSLAND/YALE UNIVERSITY

SELF STUDY Stanford professor Michael Snyder, shown here in his lab, was the subject of his own research on markers for diabetes.

ENERGY

# Smarter Biofuel Bugs

## A molecular sensor boosts biodiesel production

**SOURCE: "DESIGN OF A DYNAMIC SENSOR-REGULATOR SYSTEM FOR PRODUCTION OF CHEMICALS AND FUELS DERIVED FROM FATTY ACIDS"**
Jay Keasling et al.
*Nature Biotechnology,* published online March 25, 2012

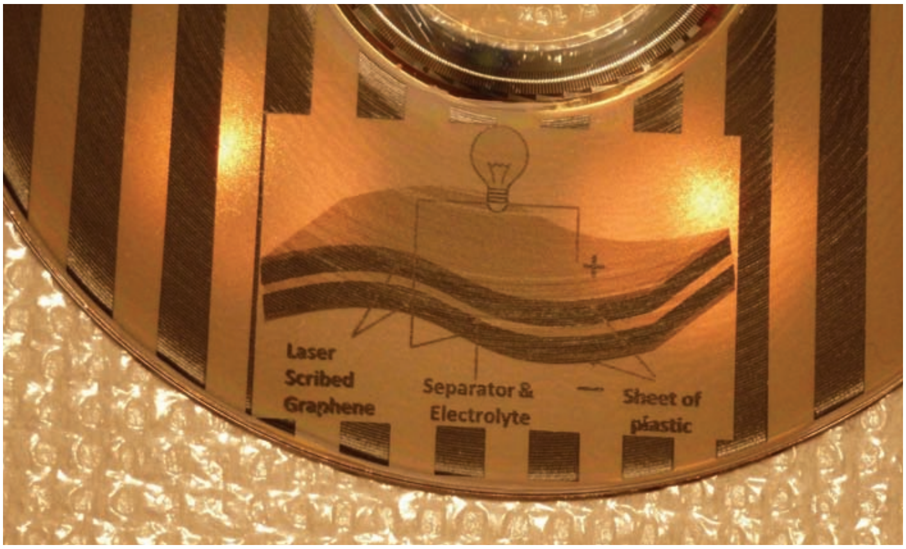
**RESULTS:** Synthetic biologists in California demonstrated a way to triple the amount of biodiesel a type of bacteria can make from sugar. They equipped the bacteria with a protein that senses the level of certain biological chemicals in a cell and changes gene activity in response. This creates a feedback loop that continually optimizes fuel production.

**WHY IT MATTERS:** Biofuels have trouble competing with fossil fuels in part because organisms are inefficient factories: they make too much of one ingredient or another. The researchers reduced that waste. This new approach could ultimately make biofuels less expensive.

**METHODS:** The researchers started with a strain of designer *E. coli* that creates biodiesel from two biological building blocks: fatty acids and ethanol. They engineered the bacteria to produce a naturally occurring protein that can sense the amount of fatty acids in a cell and regulate the activity of various genes in response. The researchers modified the bacterial genome to specify which genes the protein would control—directing it, for example, to slow production of ethanol when fatty-acid levels are low and to speed it up when they are high.

**NEXT STEPS:** Yields need to improve further for commercial production; even at triple what they were, they're still at only 28 percent of the theoretical maximum. The researchers will now try to introduce similar gene-regulating mechanisms that can improve other parts of the process or be used to make a variety of chemicals in addition to biodiesel.

ENERGY STORAGE The dark areas on this DVD are graphene, a form of carbon that can be useful for battery electrodes.




MAHER EL-KADY, UCLA

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MATERIALS

# Burning Batteries

## A DVD drive can make high-energy electrode materials

**SOURCE: "LASER SCRIBING OF HIGH-PERFORMANCE AND FLEXIBLE GRAPHENE-BASED ELECTROCHEMICAL CAPACITORS"**
Richard B. Kaner et al.
*Science* 335: 1326–1330

**RESULTS:** Researchers used an inexpensive process to build high-performance supercapacitors, which are a type of battery. The new devices store five to nine times more energy by weight than conventional supercapacitors and can be charged almost five times faster. They can also be recharged more than 10,000 times without losing storage capacity.

**WHY IT MATTERS:** The advance might bring down the price of batteries for hybrid and electric vehicles. Much of the bulk and cost of battery packs in these cars arises from measures that are necessary to help them last the life of a car. Supercapacitors are far more rugged, so they don't require these measures, but conventional ones store too little energy to be practical. The researchers found a way to increase supercapacitors' energy storage to levels that are useful in hybrid vehicles, and they found a potentially cheap way to make them. Bending the devices doesn't damage them, so they could be used to power future flexible electronics.

**METHODS:** To make supercapacitor electrodes, the researchers coat a DVD with plastic and then with a layer of inexpensive graphite oxide. They load the DVD into a standard DVD burner and use the drive's laser to heat the graphite oxide. The heat drives off oxygen, leaving behind sheets of carbon in a form called graphene. As the oxygen bubbles out of the material, it produces a network of pores that allows ions from an electrolyte to flow through the material, which is essential for high energy storage.

**NEXT STEPS:** The researchers are meeting with several companies to discuss commercializing the technology. They are also developing a processing setup that can accommodate electrodes bigger than a DVD but still uses inexpensive lasers. tr

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**EmTech Spain**
November 7-8, 2012
Malaga, Spain
www.emtechspain.com

# Books on Tape

A group led by Harvard academics hopes to compile a library of everything. One forward thinker from 1961 might have asked: What took you so long?

By TIMOTHY MAHER

A group at Harvard is trying to do online what would have been impossible before the Internet: compile a library of nearly every book available *(see "The Library of Utopia," p. 54)*.

The project is ambitious, but the idea, or something similar to it, is nothing new. One examination of the concept came in a May 1961 article in *Technology Review* called "How Will You Obtain a Book in 2000 A.D.?" The piece covered a speech by John G. Kemeny, the chair of Dartmouth's math department (later the college's president and a developer of the BASIC programming language), who advocated what he called the "automated national library."

*This library for 2000 A.D. would start with 10 million volumes and possibly grow to 300 million within the Twenty-first Century. Each page of each "book" in it would be stored on possibly a square millimeter of tape. The library would serve 100 or more universities, each of which would have a multitude of viewing screens. Using the library would be similar to making a long distance telephone call: When the patron dialed the correct code number, the reference he wished would appear on his viewing screen.*

Of course, one potential problem would be that multiple people would request the same item at once. Kemeny anticipated this: under his system, anyone asking for a particular book wouldn't get the original volume but a copy.

*The item asked for would be transferred from the storage tape to a projection unit and sent, conveniently magnified, to a tape in the reading room of the person desiring it. With $10 worth of tape, a customer could have a 10-volume collection of personally selected items; and if he tired of them, he could simply erase the tape and have a new set of books flashed to him from the master tapes in the central library. One day of each month, however, each branch of the central library might have to be closed for updating, extension, and repair of its master tapes. This, of course, would be only a slight inconvenience.*


Kemeny felt that the libraries of 1961 were already "practically obsolete" and would be "useless for most purposes by 2000 A.D." But who would pay for his elaborate upgrades? He conceded that the project might cost $1 billion, but he argued that this might compare favorably with the cost of a hundred separate universities maintaining a hundred libraries.

*The library of the future will have to make use of automation. There is no conceivable way in a library of several tens of millions of volumes that human effort could locate an item in a matter of minutes ... Storage methods must miniaturize books and put them on a medium easily handled by machines.*

This sounds vaguely Internet-like, but Kemeny wasn't predicting the Internet, exactly. He made no mention of anything like hypertext, for instance. But he did foresee the utility of being able to retrieve information over a phone line and view it on a screen from many miles away. He also recognized that once we'd compiled such a massive amount of material, we'd need some way to sort through it—in other words, a search engine.

*I am particularly attracted to the prospect of combining this automated library with machine-search ... It is possible that, even with all this elaborate mechanization, information retrieval will become hopeless in 100 years—but without mechanization we won't stand a ghost of a chance.*

Kemeny also hit on what would turn out to be one other benefit of the Internet age: the ability to get what you need without leaving your chair.

*I find the concept of such a library very attractive. I am basically a lazy person. I would like to sit in my office and have access to a book with no more trouble than calling a friend on the phone long-distance.* tr

TIMOTHY MAHER IS *TR*'S ASSISTANT MANAGING EDITOR.

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It only takes a second for
an accident to happen.
Why should it take forever to fix it?
Business responds faster because
data does more in the AT&T network.
In here, intelligent data automates all the right
actions, at all the right points, all at the same time.
Details of the accident are collected and distributed.
Insurance claims are filed and reviewed. Parts are
preordered; paint colors are premixed.
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